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Factors to consider in improving the flat panel TV display user's experience on image quality terms

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Presentada por:

Dª Berta García Castiella

Dirigida por:

Dr. Luis Núñez Ladeveze and Dr. Damián Ruiz Coll

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ABSTRACT

In the constantly changing world of image technology, many new tools have emerged since flat panels appeared in the market in 1997. All those tools went straight to the TV sets without any verification from the filmmaking or advertising industry of their contribution to the improvement of the image quality.

Adding to this situation the fact that each tool received a different name according to the manufacturer, this new outlook has become complex and worrisome to those industries that see their final products modified and have no option of action.

As for the final user, if she/he does not have prior training, it has become increasingly complicated to navigate through the menu, find the desired option or understand what this tool does and how to modify it.

In this new scenario, both the content producer and final viewer are absolutely powerless, the first one being unable to control the final state of its product, the second unable to understand or react to the state of the products.

The thesis here presented offers results of research on how those new tools modify the image quality, how this is perceived by professionals of the flat panel TV industry and cinematography experts and how it is perceived by the final user.

The objective of gathering this information being the reaching of conclusions on how to solve this current situation of image quality instability.

KEY WORDS

Flat panel TV display, motion interpolation, image modes, HDR effect, scaling system, resolution, image quality.

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1. Introduction

1. Introduction

Since large flat panel TV displays[i] first arrived in 1997 they have introduced new signal processing systems that were not present with old CRT[ii] TV sets due to the necessity of adapting the video format sequences to the particularities of their light emitting system.

This happened with both backlit panel TV displays[iii], mainly LCD[iv], and with emissive panels[v], mainly plasma[vi] and OLED[vii].

All those different flat panel displays require adaptation of the different spatial resolutions[viii], SD[ix], HD[x], 4K and 8K (UHD)[xi], with which the audiovisual contents are broadcasted, to the native resolutions of their

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[i] A flat panel TV display is a technology that was born in 1964 and arrived into the market in 1997. There are two different kinds of flat panel displays: emissive (plasma and OLED) and backlit (LCD, LED and QLED).

[ii] Cathode Ray Tube. Old non-flat screens. One of their main characteristics is that the lines displayed on a CRT are not appearing all at the same time but from left to right and from top to bottom first the even lines and then the odd ones filling the gaps.

[iii] The main characteristic of a backlit panel is that it never turns its light off. There is always a light remanence at the back of the panel.

[iv] Liquid Crystal Display. This is a backlit flat panel display that uses polarizers and liquid crystals to make the stream of light reach the screen.

[v] The main characteristic of an emissive panel is that it creates the light it emits, it is not backlit, every pixel creates its own light.

[vi] This is an emissive flat panel display whose technology applies current to a rare gas to transform it into plasma gas. Thanks to the nature of plasma gas and the walls of the tube coated with phosphor, this results in visible light.

[vii] Organic Light-Emitting Diode. This is an emissive flat panel display whose technology is based upon diodes coated with a layer of organic components that, with a determined electric stimulation, emit light of a determined wavelength (color).

[viii] The number of pixels utilized to construct the image.

[ix] Standard Definition. TV format that defines the spatial resolution of the images that compose the video sequence. In Europe, the PAL system establishes a resolution of 576 lines and 720 pixels per line. In USA, the NTSC system establishes a resolution of 480 lines and 720 pixels per line. Both formats use interlaced scan.

[x] High Definition. TV format that defines the spatial resolution of the images with two formats: 720p and 1080i. The first format draws 720 lines and 1280 pixels per line with progressive scan, the second format draws 1080 lines and 1920 pixels per line with interlaced scan.

[xi] Ultra-high Definition. TV format that defines the spatial resolution of the images with two formats: 4K and 8K. The first format, 4K, draws 2160 lines and 3840 pixels per line or 2160 lines and 4096 pixels per line, even though those two formats are not the same (their aspect ratio varies) we will refer to them both as 4K from now on (even though 3840 is UHD and 4096 4K) since this is what is done in the industry. The second format, 8K, draws 4320 lines and 7680 pixels per line. Both with progressive scan.

panels. This process involves different digital signal processing techniques called scaling[xii].

Flat panel TVs have to adapt as well to other parameters like the bit depth[xiii] and the different color space[xiv] standards used for commercial purposes. According to the recommendations from the ITU[xv]; BT.601[xvi] for SD, BT.709[xvii] for HD and new BT.2020[xviii] for UHD[xix]. In addition, this requires a very strong signal processing system.

As with the aforementioned parameters, flat panel TVs have to adapt to and process the different refresh rates[xx] and frame rates[xxi] that vary in their capture method (progressive[xxii] or interlaced)[xxiii] and in their frequency; 24fps, 25p, 30p, 50i, 30i, 50p, 60p until most modern frequencies for UHD like 120fps.

Undoubtedly, this temporal processing of contents to the particularities of the flat panel TV display technology is the most demanding

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[xii] is a form of video processing in which by using an interpolation algorithm, the panel adapts the amount of pixels of the contents to its native resolution.

[xiii] The video and image formats use discrete integer values to represent the luminosity level of each pixel. As a general rule, in the digital environment, a base 2 representation is used, where each digit is a bit and thus, the number of possible values to obtain on this base is of 2 elevated to the number of used bits. In digital video, the regular standard is 8 bits, which implies 256 possible luminosity levels per pixel. Nowadays video cameras can capture up to 16 bits. With the new 4K format, 10 bits is the new standard.

[xiv] A specific organization of colors that relates colors to numbers in a three-dimensional form (X,Y and Z) that can form all possible color combinations within the gamut.

[xv] International Telecommunication Union, founded in 1865. The ITU-R are the recommendations that the ITU has been launching throughout the years in terms of image quality and regulations for standards.

[xvi] Standard recommendations from ITU for SD TV broadcast.

[xvii] Standard recommendations from ITU for HD TV broadcast.

[xviii] Standard recommendations from ITU for UHD TV broadcast.

[xix] Ultra-high Definition. TV format that defines the spatial resolution of the images with two formats: 4K and 8K. The first format, 4K, draws 2160 lines and 3840 pixels per line or 2160 lines and 4096 pixels per line. The second format, 8K, draws 4320 lines and 7680 pixels per line. Both with progressive scan.

[xx] Is the number of times per second that the display device refreshes or draws the picture or frame on the screen.

[xxi] Is the number of different pictures or frames captured by the camera per second.

[xxii] the progressive scanning system draws all the lines that form the picture on the screen at the same time.

[xxiii] the interlaced scanning system draws the lines that form the picture on the screen in alternating fashion, first odd lines and then even lines from left to right from top to bottom.

on computational terms, but as well the one that has more influence on the viewer's quality experience.

A last parameter that flat panels have to adapt to is the dynamic range[xxiv]. Recent improvements in this area have shown the importance of high dynamic range (HDR[xxv]) for human perception of image quality. Nevertheless, the ability of the panel to increase the range from a standard dynamic range (SDR[xxvi]) content has still room for improvement.

Due to all these new signal processing techniques a new question regarding the quality of the image arises: Which factors are now going to affect our perception of the quality of motion pictures on a flat panel TV display?

And from this consideration arises a new one: to wonder which features from the content we are watching on our flat panel TVs are being created by the panel and which were actually intended by the creator of the content?

1.1. Study object and justification

The study object of this research is the different elements that interfere in the human perception of motion picture quality on flat panel TV displays and how they interact amongst themselves.

This study is carried out with the intention of diminishing the increasing lack of information and ignorance from users and consumers

[xxiv] The difference between the darkest black and the lightest white of an image, the larger the dynamic range, the more different brightness values the image has. We can measure the dynamic range in f-stops on a camera or in contrast ratio such as 100:1 (100 being the white and 1 the black) on a panel or projector.

[xxv] High Dynamic Range. An HDR image has around 17 f-stops of dynamic range.

[xxvi] Standard Dynamic Range. An SDR image has around 6 f-stops of dynamic range.

regarding the basic concepts related to the image quality perception, that leave them without their own decision capacity.

This is exactly what happens with flat panel displays. Manufacturers disguise their new technologies with bombastic names that boast the latest technology and, therefore imply, the best of image quality. Nothing could be more untrue.

What this research claims is to provide users with a basic knowledge of the elements that actually affect our perception of the image quality on a flat panel TV display in order to give them enlightened decision power.

It also claims to raise consumer awareness that not all kinds of contents require the same viewing tools. Thus not all kinds of consumers will need the same kind of flat panel TV display nor the same selection of viewing tools. This decision should be based on the user's content preferences.

1.2. Hypothesis

Our **first hypothesis** states that most of the elements so far considered as crucial for the improvement of the image quality perception on a flat panel TV display are not crucial at all on these terms. The most prominent example of this statement is possibly the importance given by the flat panel TV display industry to the increase of spatial resolution with the HD and new 4K and 8K formats.

Our **second hypothesis** states that not all kinds of contents require the same viewing tools from a flat panel TV display. For example, a sports content may require a higher temporal resolution[xxvii] than a cinematographic

[xxvii] Is the number of frames displayed per second.

content where contrast, colors and above all, the respect for the artistic decisions taken by the filmmaker are essential.

Our **third hypothesis** states that the perception and appreciation of these quality features on a flat panel TV display depend on the kind of consumer in terms of visual perception and importance given to the image quality.

1.3. Objectives

To carry out this study we have both; general and specific objectives based on the needs arising from the study object.

1.3.1. General

Know and disclose the opinions and criteria of flat panel TV display industry professionals and cinematography professionals on the different factors that affect image quality on flat panel TV displays.

Know and disclose the opinions and criteria of flat panel TV display industry professionals and cinematography professionals on the question: do all contents require the same display tools?

Study the perception from flat panel TV display industry professionals and cinematography professionals of the image quality on flat panel TV displays.

Study the perception of consumers of the image quality on flat panel TV displays.

1.3.2. Specific

Suggest technical solutions to allow both consumer and flat panel TV displays to identify the different kinds of contents.

Create a consultancy blog to inform users and manufacturers of the results of this research in order to provide them with tools that will allow them to choose their products with decision power.

1.4. Methodology

The methodology that this research has followed is empirical, descriptive and historical.

We ran an historical research for our historical and state of the art context, since it provides data collection of events that occurred in the recent past and does a narrative exposition of it.

We did a descriptive research for our theoretical framework. This section provides an accurate portrayal of characteristics of a situation describing what exists and categorizing information.

We finally chose an empirical research for our fieldwork. We gain knowledge by means of direct observation and experience. This empirical evidence was gathered using both quantitative and qualitative methods.

For our consumer panel we used a quantitative method such as the survey to collect data that could provide us with information to help us answer our hypothesis.

For the rest of the fieldwork we used two qualitative methods; the one-on-one interview to get information from experts and professionals and a focus group to put their opinions together and get to conclusions (Bhat, 2016).

1.4.1. Research design

We organized our fieldwork according to our project's needs as follows;

In order to reach the objectives, this investigative project confronted:

- Technical criteria from flat panel TV display industry professionals with technical criteria from cinematography professionals on which factors actually affect image quality on flat panel TV displays.
- Opinions and criteria from flat panel TV display industry professionals with technical criteria from cinematography professionals on the question: do all contents require the same display tools?
- Opinions from flat panel TV display industry professionals and cinematography professionals with those from consumers on the perception of image quality on flat panel TV displays.

We considered that the most effective way to test whether a viewing tool is satisfactory is by asking regular consumers, if regular consumers reject it or are not able to notice any difference, this tool may not be performing as well as designers had planned.

Since flat panel TV displays first appeared image technology has evolved so much that the time has come to bring together professionals and consider which of the new tools are contributing to improve the image quality and which may not be as important as first thought.

On this point, the most affected position is that of the cinematographer and the colorist, two jobs that are extremely related with the aesthetic purpose of a motion picture and, when it comes to the device, that of the engineer.

Therefore, we considered that representatives from these two specializations should discuss the matter in order to reach a conclusion or different positions for different reasons.

1.4.1.1. Method to figure out the professional's judgment (professionals from flat panel TV display industry and cinematography)

We carried out 6 interviews with professionals from both fields[xxviii], flat panel TV display industry and cinematography, to know their opinions and criteria on the factors that actually affect image quality on flat panel TV displays and, on their opinions and criteria regarding the question: do all contents require the same display tools?

We considered that, with two cinematographers, one coming from the advertising background and another one from the cinematographic background we should have a solid point of view from the field. We also needed to include a colorist (working for both, advertising and motion pictures), this being the other profession more affected by new flat panel TV displays.

As for the flat panel TV industry, we decided that we needed a representative from each one of the most important brands in the market, namely Samsung and LG, the brands with more flat panel TV display sales in Spain in year 2018, and Sony running far behind; We actually interviewed one representative from each brand but we only carried out our consumer panel with LG and Samsung devices.

1.4.1.2. Method to figure out how consumers perceive image quality on flat panel TV displays

We carried out a consumer panel with a random sample of 45 people where the following test took place:

All members of the consumer panel were asked to watch on flat panel TV displays of different brands and models (4K 65'' OLED -LG- and

[xxviii] See annex 1

QLED[xxix] -Samsung-) a selection of contents recommended by professionals organized as follows;

- Motion interpolation tool on and off with sport and cinematographic contents.
- Sport and cinematographic contents with both HD and UHD resolution.
- HDR[xxx] effect on and off with TV and cinematographic contents.
- Image mode designed for sport and cinematographic contents on and off with sport and cinematographic contents.

All members of the consumer panel were asked to answer a survey[xxxi], elaborated from the answers of the experts to the interviews, to learn which parameters of the image quality from the flat panel TV displays they preferred on or off and which ones they perceived or not.

We analyzed the results from the survey.

Since we could only carry out the fieldwork in Spain as this is where our research University is located, we took the reference Universe of its population (46 million inhabitants, minus those between 0-14 and those older than 64, which was 32 million inhabitants).

The population between 0-14 and older than 64 was not considered in the sample since the results are more likely to be affected by eyesight issues.

With a Universe of 32.000.000 with a heterogeneity of 50%, we wanted to get a 95% of confidence level and a 15% of error rate; Consequently we had to have a sample of 43.

We thus decided to test a random sample of 45 people in order to have a sample as representative as possible (we had people from 22 to 55

[xxix] Quantum dots light-emitting diode. A backlit panel display whose technology uses small semiconductor particles that emit light of different colors depending on their size when current is applied to them.

[xxx] High Dynamic Range. An HDR image has around 17 f-stops of dynamic range.

[xxxi] See annex 2.

years old, 47% women and 53% men). With this random sample it should be enough to draw conclusions.

1.4.1.3. Method to share opinions and criteria from professionals from flat panel TV display industry and cinematography

We carried out a focus group with six professionals (from the flat panel industry and cinematography) coordinated by an expert, an image engineer.

We performed with the professionals the same test done previously with the consumers and made the members of the focus group watch on flat panel TV displays of different brands and models (4K 65'' OLED -LG- and QLED -Samsung-) a selection of contents recommended by professionals organized as mentioned before.

We made the members of the focus group see the results of the surveys from the consumer panel.

We discussed; the questions from the interviews; as well as the results from the consumer's surveys and discrepancies (if any) on the technical criteria from the different experts on the factors that affect the image quality on flat panel TV displays.

The same process was carried out to discuss and reveal discrepancies, if any, on the opinions and criteria from the different experts on the question: do all contents require the same display tools?

We analyzed the answers and discussion from the focus group.

We decided that the focus group would be the best tool to put all the data together and have professionals discuss the results from the consumer panel as well as their different points of view on the different tools and their performance. (Devault, 2019)

2. Historical Context

2. Historical context

Before talking about the numerous features of the different flat panel technologies available today, we will quickly go through the evolution of these technologies from the historical point of view.

This approach will hopefully provide us with a wider perspective of the actual situation that panel TV display devices are experiencing now.

2.1. The first panels

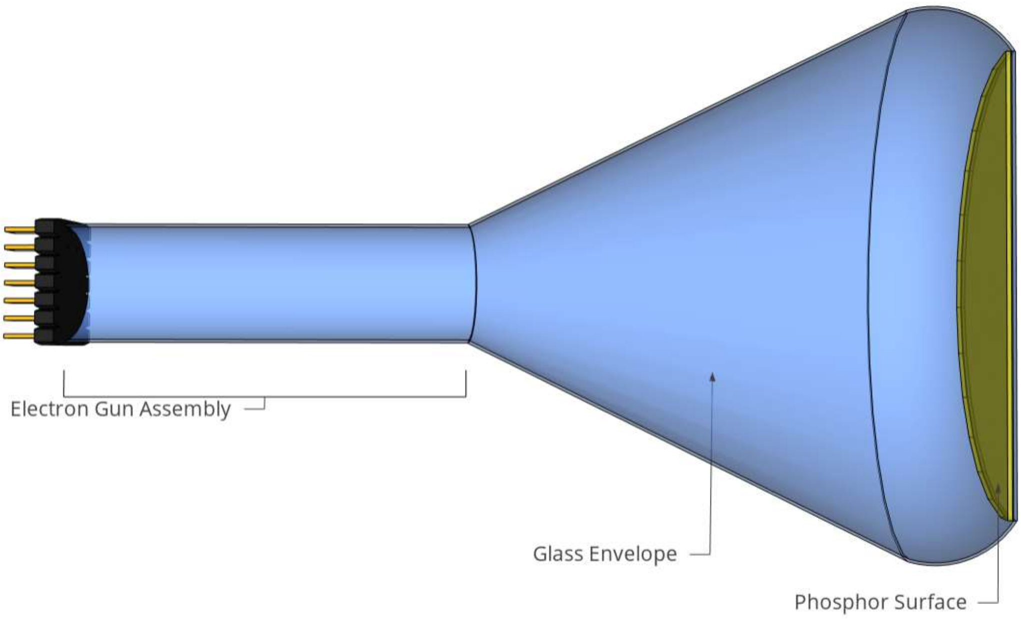
When in 1926 John Logie Baird invented the first working television, he used a CRT because flat panel technology was not ready yet, but engineers had started research on its development since television was born.

The CRT was invented in 1897 by Karl Ferdinand Braun (this is why the panel is also known as “Braun tube”) and, even though since the 1950s an enormous effort was made by the industry to develop a technology to effectively substitute the CRT, in the 1980s it was the only commercially available device (Tannas, 1985).

What is a CRT and how does it work? A Cathode-ray tube is formed by three different parts; the electron gun assembly, the phosphor viewing surface and the glass envelope.

Electrons are emitted from the cathode at the rear of the gun in a beam accelerated by a high voltage at the anode surrounding it. The deflection coils will steer the electron beam to strike the phosphor surface in a side to side scanning motion starting at the top of the surface and working down. When struck by the electron beam, the phosphor surface emits visible light. The glass envelope protects all the elements inside the gun and the phosphor surface.

Figure 1. CRT structure



Source: designed by the author

In 1950, RCA (Radio Corporation of America) introduced the shadow mask color tube. This improved the CRTs' brightness and luminous efficiency and the technology continued to improve at lower and lower prices and with many options in sizes and shapes.

This is probably why it took so long for the industry to launch a product that would definitively replace CRTs. But the digital era invaded every technology field, including the panel TV display industry.

2.2. The first flat panels

The first flat panel was invented in 1964 by two professors and a student from the University of Illinois, it was the beginning of the plasma technology, the first digital prototype.

They were referred to as “flat panels” to mark the difference between them and old CRTs since they were all thin in form and they had lower volume. The common feature of all non-CRT panels is that they were thinner than their predecessor.

Although the obvious value of flatness was economy of space, other features were expected from the new generation of panels such as; high resolution, high contrast, lightweight, solid-state, low power consumption, sunlight readability, better color performance, etc (Tannas, 1985).

Even though they were invented in 1964, flat panels did not fully reach the market until the 1990s.

In October 2004, the Consumer Electronics Association in the US found through a survey that plasma TV was the most desired gift for Christmas, but before this, the technology struggled for decades and faced many challenging problems.

The devices made by the University of Illinois proved the fundamental concepts but were too fragile for commercial products. It was the company Owens-Illinois who first delivered a plasma display panel in 1971. But it was not until 1992 that the technology matured with the prototype of color plasma display designed by Fujitsu (Weber, 2006).

In 1996, the first large flat panel TV display was designed and launched in 1997 by Panasonic, it was the great start of Plasma technology. As we mentioned before, in 2004 Plasma technology was at its peak of popularity, but this success was not to last long. In 2004 the first LED-backlit LCD TV was introduced by Sony, a model with a color gamut about twice that of a conventional CCFL (Cold Cathode Fluorescent Lamp) LCD TV.

In 2006, LCD technology started competing with Plasma. Even though liquid crystals were discovered by the end of the 1880s and patented in a practical application by 1936, it wasn't until 1962 when RCA discovered their properties for what was called "electro-optical effects" and by 1964 the first liquid crystal display was invented.

In 1972, Westinghouse in the US, produced the active matrix LCD panel. In the 1990s Hitachi and NEC were the first manufacturers of active matrix LCDs but this technology was still critical to large screen LCDs.

In 1996 Samsung developed optical patterning for multi domain LCDs. It was then that the LCD industry moved from Japan to other countries such as South Korea and Taiwan. As mentioned before, in 2006 the two main technologies available in the market were competing ferociously. Instead, CRTs were no longer popular, in 2008 Sony stopped manufacturing CRTs and by 2014 India, even with its vast market stopped producing them (Roberston, 2018).

The situation was no better for plasma technology, in 2011 Toshiba improved LCD technology producing a higher resolution and larger LCD panel for tablet computers. In 2013, Panasonic stopped manufacturing plasma panels, as did LG and Samsung in 2014. By 2016, plasma technology was no longer available on the market.

When the first LED-backlit LCD TVs appeared in 2004, they became very popular due to the evolution of energy standards and expectations regarding power consumption. It took only ten years for the rest of the technologies to disappear (Kennemer and Waniata, 2019).

The first OLED TVs started shipping in 2013, manufactured only by LG (Morrison, 2017) They were quickly applauded for their black level performance that same year, but they still couldn't compete with LED LCDs on brightness levels and there was a huge price gap between the two technologies (Cohen, 2019).

At the same time in 2013 another technology arrived from the Sony company, by that time called “Triluminos”. Even though the idea of using quantum dots as a light source started in the 1990s, it wasn’t until the 2000s that scientists started developing this technology for light displays. In 2017, Samsung rebranded the technology as “QLED”.

Now both technologies, OLED and QLED are competing on the high-range products while LED LCDs are at the line of more affordable prices.

When it comes to the basic quality features of both OLED and QLED technologies such as black level and contrast, refresh rate, eye comfort, viewing angles, etc. experts still prefer OLED performance over QLED. But QLED is better on prices, screen burn-in and size. Only power consumption is the usability feature in which OLED is now superior to QLED and consumers are generally more interested in those features (Levenson, 2019).

Figure 2. Panel timeline

Source: designed by the author

3. State of the art

3. State of the art

Since the first large flat panel TV displays arrived on the market in the 1990s, several features have been appearing for the purpose of improving the user's experience. Some were meant to adapt the native resolution of the content to one of the panels, others appeared to add motion smoothness to the image and there were features to improve the image's dynamic range and even some to modify image values such as color temperature, brightness or saturation. All those features started to appear on the new flat panel displays but manufacturers didn't seem to have carried out accurate motion image quality tests before releasing them.

In this investigation, we wanted to have a deeper look at the scaling systems, the motion interpolation tools, the picture modes and HDR effects of new flat panel TV displays.

3.1. The scaling system

When talking about the image resolution[xxxii], since the first HD set arrived on the market, a lot of importance has been given to improving image resolution from the television industry.

In 1968, the NHK corporation (Japan Broadcasting Corporation), created a new standard to increase resolution for television broadcasting. It flourished in 1970 when Japanese engineers developed the MUSE high definition system. In 1974, Panasonic designed a prototype TV capable of displaying 1,125 vertical lines[xxxiii]. In 1980, NHK developed the technology.

[xxxii] The image resolution is the amount of pixels used to form one image.

[xxxiii] That is a remarkable increase if we consider that PAL and NTSC had 625 (576 visible) and 525 (480 visible) lines at that moment.

In 1987, the president of the NAB (National Association of Broadcasters) in the United States brought representatives from NHK to Washington D.C. to show the HDTV technology. After that, the ACATS (Advisory Committee on Advanced Television Service) was created to decide the set of high-definition standards in the US. With the purpose of designing those standards for the ACATS to approve, several companies came together to create the Grand Alliance. When ACATS approved their standards, the first HDTV arrived on the US market in digital form in 1998 from Panasonic and Sony (Strickland, 2009).

Being such a new product, a lot of studies are still being run in order to establish how all the different resolutions can adapt to each other in the best possible way. Not just the different resolutions in broadcasting services and display devices but more importantly, the huge differences arising between the resolution of the broadcasting services and the display devices. A scaling system was needed, and it needed to be very versatile.

An interesting study carried out by the University of Nantes in 2014 upscaled 720p and 1080p sequences to UHD by using different algorithms and noticed that with fast motion contents, viewers' preferences were not significantly different. They recommended the design of a novel upscaling algorithm based on the mechanisms of the human visual system.

This study is very relevant to our investigation since it points out the need of considering the human visual system in order to design the algorithm. As we have seen, the human visual system requires a specific viewing distance and panel size in order to properly perceive the resolution differences in the image.

Another interesting study carried out by a collaboration between Ghent University and the Free University of Brussels in 2016 tested a non-expert participant population to differentiate between native 4K and upscaled HD video and notice that the results were very content dependent.

This is very interesting to us since it shows that not all contents require the same viewing tools from the flat panel TV display. The study contributed to the research process of developing metrics indicating visibility of high-resolution features within specific content.

3.2. The motion interpolation tool

In 2008 the first LCD TV sets with motion interpolation appeared. Some of the first panels to have it were Samsung LN52A650 and LG 47LG60. Also, one Plasma panel with motion interpolation appeared but it did not succeed much since it introduced too many artifacts.

By August 2008, viewers started asking experts on pages like CNET about the new motion interpolation tool (by that time called de-judder tool) after sharing their first impressions about how weird the looks were (at that time called "video like", "real life like" or simply "unnatural"). (Katzmaier, 2008)

In 2009, LCD dominated the market over Plasma.

Also, in 2009, viewers and experts started posting on pages like Techcrunch their impressions and side effects of the motion interpolation tool, the name "soap opera effect[xxxiv]" was born. (Biggs, 2009)

In 2010, the first posts about motion smoothing and several TV settings appeared on pages like Techhive to start explaining to viewers what those tools were and why movies would look different on their TV sets. (Arar, 2010)

[xxxiv] Side effect resulting from watching fiction contents with the motion interpolation tool on that gives a new look to the contents where everything seems to be recorded on video instead of film.

In 2011, the first blogs and webpages like Prolost started talking about motion interpolation and image modes and explained to viewers how to turn them off. (Maschwitz, 2011)

In September 2012, some directors (including British film directors Michael J Bassett and Neil Marshall) launched a campaign to make sure films were watched as the director intended. The website AV Forums published a series of instructional videos to help people tune their sets. (BBC, 2012)

Back in year 2014, the cinematographer Reed Morano, from ASC, started a request to all broadcasters and flat panel TV display manufacturers to stop motion interpolation. 13.185 people have signed since. (Morano, 2014)

In summer 2017, before the release of the second season of the series *Stranger Things*, the creators, the Duffer Brothers, warn the viewers saying that they should turn the motion interpolation off on their TVs to watch the contents as they intended. (Karan, 2017)

In September 2018, Christopher Nolan and Paul Thomas Aderson reached TV manufacturers through UHD Alliance to start a dialogue on how new technologies could ensure that home viewers see their work presented as closely as possible to the original creative intentions. They were asking for a reference mode. (*experienceuhd*, 2019)

In December 2018, before the release of *Mission: Impossible Fallout*, Actor Tom Cruise and Director Christopher McQuarrie, launched a presentation video in which they informed the audience about how unfortunate the soap opera effect was and how to deactivate motion interpolation on their TV sets. (Spangler, 2018)

There are thousands of websites nowadays, some having started posting back in 2010, explaining step by step how to turn all those settings off like Tom's guide, with pages like "How to disable motion smoothing on your TV right now for a better picture". There are online articles, like the one from the Independent entitled "What is motion smoothing and how do you turn it off?".

On the 27th of August 2019, the UHD Alliance (a coalition whose members include Hollywood studios and consumer electronics manufacturers) and a team of filmmakers (including Martin Scorsese, Christopher Nolan, Ryan Coogler, Patty Jenkins, Rian Johnson, …) announced the agreement of creating a new TV setting called the "filmmaker mode", an option to preserve the creative intent of filmmakers (color, aspect ratio, frame rate, …) on the consumer displays. (Giardina, 2019)

In January 2020, Panasonic announced at CES[xxxv] 2020 in Las Vegas that they would launch the first flat panel TV display with Filmmaker Mode and Dolby Vision IQ[xxxvi], the HZ2000 OLED. This panel is not yet on the market but will arrive during 2020, probably before the Olympic games of Tokyo (Garreffa, 2020).

As we can see, this is a matter that concerns everyone involved in the industry but also and more importantly, viewers. All those websites posting instructions to guide viewers on how to turn a setting off were born out of a big need. The truth is that by typing online the words "motion interpolation", 9 out of 10 pages appear to explain how to turn it off.

In year 2012, Samsung Electronics carried out a study to test a new motion interpolation tool. They manage to eliminate in 24Hz film source motion judder thanks to a motion compensated frame interpolation with a 120Hz frame rate. But there was no test with non-expert users to see their

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[xxxv] Consumer Electronics Show. World's gathering place for business of consumer technology. Owned and produced by the CTA (Consumer technology association). (Osborne, 2020)

[xxxvi] Dobly Vision IQ is a new feature that uses dynamic metadata encoded in Dobly vision content in conjunction with an embedded light sensor in the panel using the resulting information to change picture settings and display a more accurate picture. It can detect the brightness in the room and boost the brightness of the panel to adapt it automatically. It can also adapt picture settings based on content using dynamic metadata instead of AI deep-learning. (Pino, 2020)

preferences. This gives us again an idea on how those tools are implemented in the market.

In 2016, a study carried out by a collaboration between the University of South California and the Electronics and Telecommunications Research Institute of Daejeon, South Korea, tested the PQD-FRS (perceptual quality driven frame rate selection) tool. This tool assigns a varying frame rate to a sequence so as to reduce its transmission cost (bandwidth). In their results the PQD-FRS could be applied without any perceptual quality degradation for a majority of viewers.

This study is very interesting to us since is not only varying the original frame rate but doing it constantly. Which means the viewer will not watch the same frame rate during the viewing, but a varying frame rate in order to reduce bandwidth.

3.3. The picture modes

When both digital and high-definition flat panel TV displays arrived on the market in the late 1990s, the product out of the box looked extremely bright with over-exaggerated color palettes. This was because they came with the so called “dynamic or vivid” picture mode on.

Nowadays users are getting more used to the process of setting a new TV set but still not enough as shows our survey (a 65,2% never adjusted their picture mode according to the content they were watching and 15,2% didn’t even know if their TV sets had picture modes) (Maxwell, 2015).

A United States patent from 2001 called “System and method for automatic audio and video control settings for television programs” shows a very interesting example of the topic we are addressing.

It developed a system for automatically adjusting characteristics of a television receiver such as the video and audio settings based on characteristics of the program being viewed, by accessing a pre-defined list of program topics and themes stored in a TV database.

An example would be:

Grid 1. Image element values for fiction contents

Topic	Theme	Contrast Level	Color Level	Brightness Level
Movies	Action	+3	0	0
Movies	Comedy	+3	0	+1
Series	Drama	0	0	0

Source: designed by the author

This is a perfect example of how the TV set is actually designing the aesthetics of the contents. In the case of this patent, it takes into account the different kind of content according to the genre, which implies that all genres will always have the same aesthetics by default. We only took the example with the image, but the system does exactly the same process with the audio signal.

Grid 2. Sound element values for fiction contents

Topic	Theme	Audio Processor	Bass Level	Treble Level
Movies	Action	Dolby Prologic	+4	+2
Movies	Comedy	Dolby Prologic	+1	+1
Series	Drama	Stereo	0	+2

Source: designed by the author

This affects all different kinds of contents, not only fiction and the TV set does exactly the same process with sport contents for example.

Grid 3. Image element values for sport contents

Topic	Theme	Contrast Level	Color Level	Brightness Level
Sports	Ice Hockey	-2	0	-4
Sports	Football	+2	+1	0
Sports	Golf	+2	+1	0

Source: designed by the author

And the same, of course, with sound.

Grid 4. Sound element values for sport contents

Topic	Theme	Audio Processor	Bass Level	Treble Level
Sports	Ice Hockey	Stadium Surround	+2	0
Sports	Football	Stadium Surround	+4	0
Sports	Golf	Stereo	0	+3

Source: designed by the author

This patent shows how TV sets should work nowadays: they apply a basic and standardized formula to every content in order to display it that does not take into account any of the specific aesthetic needs of each content. This is of paramount importance for our study since it shows how much the previous job of both the cinematographer and colorist is lost at this point if we consider a content with an aesthetic purpose like advertising or cinematography (Morrison, Crosby and Logan, 2001).

3.4. The HDR effect

In the early 1990s the first HDR still image camera was designed. It attained an HDR image by combining two simultaneously captured images.

The amazing improvement in image quality for human visual perception was quickly obvious and HDR started to interest the image industry, consumers and professionals. It was clear that human visual sensitivity towards the image's dynamic range was greater than towards other image features like resolution or color gamut.

Simply because the higher the dynamic range, the more details will be captured in the shadows and highlights (Djudjic, 2017).

In the early 2000s several companies such as RED or Arri, started developing cinema cameras with sensors capable of capturing HDR images. At the same time, the first TV sets with enhanced dynamic range and upscaling of existing SDR started developing.

In 2015, HDR 10 was announced by the Consumer Technology Association. It was an HDR format supported by a wide variety of companies such as LG, Samsung, Sharp, Sony, … but Dolby laboratories designed another competing format, Dolby Vision, a different HDR format.

In 2016, HDR + was born, a conversion of SDR to HDR video released by Samsung.

In 2017, Samsung and Amazon video announced the HDR 10+, an improved version of their previous format, and later that same year, Samsung, Panasonic and 20th Century Fox created the HDR 10+ Alliance to promote their format through Amazon video.

In 2017, a study carried out by the University of Applied Sciences in Wiesbaden, Germany tested the viewer's preferences for dynamic range. Based on the fact that modelling the human visual system can be remarkably different from creating a pleasing image based on aesthetic wishes and artistic intents, they tested the viewers' preferred dynamic range and used it to set up a model to enhance existing tone mapping.

This study is very relevant to us since it assumes as its starting point that the image quality perception is more closely related to our aesthetic culture and background than to our human visual system.

In 2018, The BBC Research and Development ran a study to explore viewer tolerance to brightness shifts of different sizes and proposed two things; a normal operating range for the main display luminance and an extended operating range for special creative effects. (Noland and Pindoria, 2018)

This is also very interesting to us since it shows that viewers rejected the extended dynamic range when it wasn't native under normal luminance conditions of the contents. Our tests showed that viewers manly rejected this HDR effect, this being perhaps due to the fact that it was applied during the entire footage and not only for special creative effects as this study suggests.

In 2018, the ITU Recommendation BT.2100 (*ITU.int*, 2018), established the standard for broadcasting HDR contents and it specified two formats; HLG and PQ. Hybrid Log-Gamma was a gamma curve compatible with SDR, Perceptual Quantization was the basis of both HDR 10 and Dolby Vision formats.

At CES 2020, a new format was launched, the Dolby Vision IQ. This is a new feature that uses dynamic metadata encoded in Dolby vision content in conjunction with an embedded light sensor in the panel using the resulting information to change picture settings and display a more accurate picture. It can detect the brightness in the room and boost the brightness of the panel to adapt it automatically. It can also adapt picture settings based on content using dynamic metadata instead of AI deep-learning (Pino, 2020).

4. Theoretical Framework

4. Theoretical Framework

Due to the difficulty of establishing reliable features to determine the motion picture quality aspects owing to their interdependence, we prefer this study to address them with a different approach and focus on its time and space units and their behaviors as well as an undeniable quality sign element: the amount of visual information and its link with the nature of the content.

It is crucial to underline first that there is still not a current way or standard to reliably determine image quality improvement.

On this basis, the amount of visual information, together with the space and time elements, should describe an accurate landscape of the motion picture quality aspects, since no other elements seem to come into play.

Besides, all these aspects will be explained in their two different states: captured and displayed. All these different points of view will certainly help us to realize the true importance of each of them and their relations. But we will also consider the type of content and how the very nature of this content affects human perception of quality.

In this theoretical framework we are going to deeply review all the aspects that take part in motion picture quality. To do so we will divide them into three blocks: Space, time and amount of visual information.

4.1. Influence elements on image quality: Space, time and amount of visual information

We intend to explain these parameters according to the three categories and all the subcategories involved in the nature of each parameter.

4.1.1. Space

A pixel is the minimum discrete unit of a picture, a picture element. For the purpose of studying pixels we will explain them according to two different features, their size and shape.

4.1.1.1. Pixel size

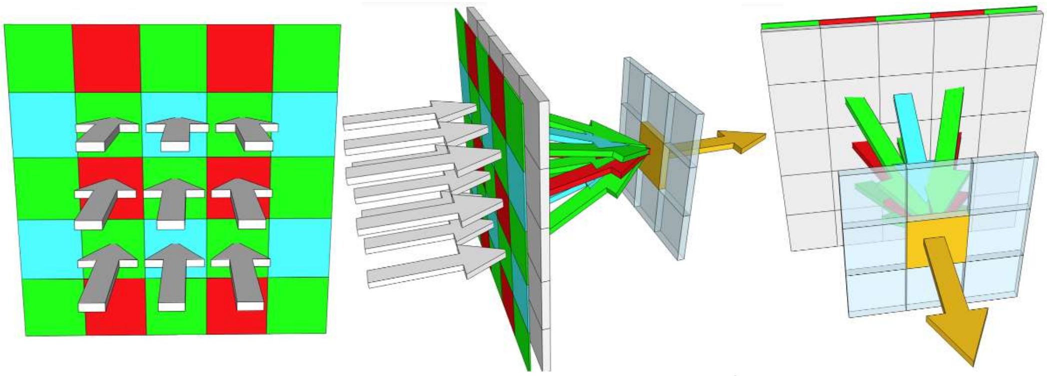
The pixel size: The unit of every motion picture is the pixel, but captured pixels and displayed pixels can be different in terms of size so we will explain them separately;

Size in captured pixels: pixels are formed by sensels (sensor elements), which are photodiodes (a semiconductor device that transforms light into electrical current) placed in lines and columns over the camera's sensor.

In for example the case of a CMOS[xxxvii], all the information gathered by a sensel is interpolated with that of its eight neighbors through a demosaicing algorithm to create one pixel in the picture. Since each sensel is capturing only one of the three primary colors, the sensor with a bayer array filter, has to approximate the other two primary colors in order to have full color at every pixel.

[xxxvii] Complementary metal oxide semiconductor. A kind of sensor used to create images in digital cameras, barcode readers, scanners and telescopes.

Figure 3. Bayer filter



Source: designed by the author

The bigger size of the sensel, the more light can be captured and thus more light information will form the picture, consequently increasing the picture quality in terms of sharpness. If we understand by picture quality the similarities between the captured image and the real one.

> *"When the resolution becomes larger for the same size of the chip, the pixel size decreases. As a consequence, some of the charge carriers generated in the silicon due to incident light may diffuse into the nearby pixels."*
>
> *(Ma and Theuwissen, 2010, p.6)*

By creating a smaller amount of pixels with a sensor of a larger size we will always create less noise and artifacts in the resulting image. (Hirsch, 2018)

> *"A sensel of large area has an intrinsically better signal-to-noise ratio than a smaller one, simply because it collects more photons. Therefore, a sensor with large sensels is inherently less noisy than one with smaller sensels designed and built with the same technology."*
>
> *(Savazzi, 2011, p.40)*

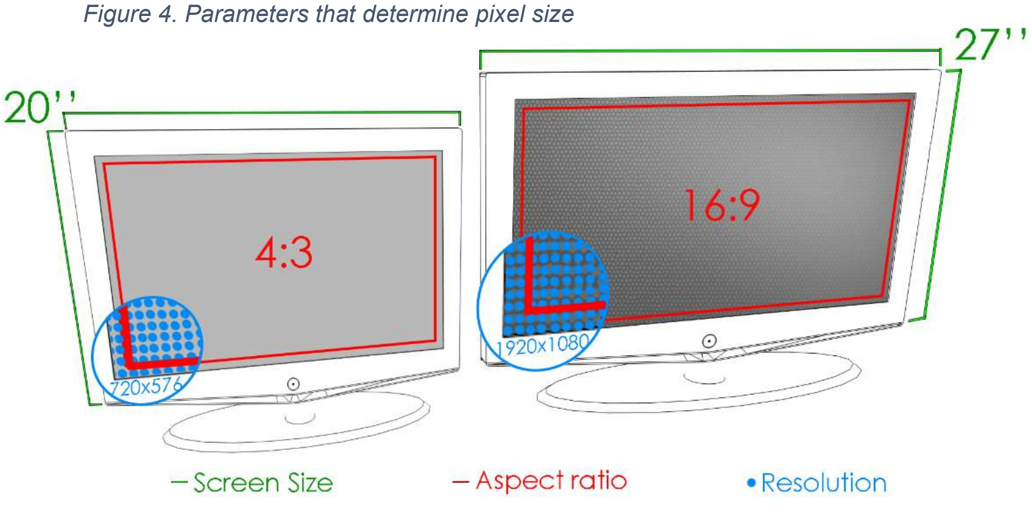
Size in displayed pixels: A pixel, as Frederic C. Billingsley called it, is a picture element. More precisely the smallest addressable element in an all points addressable display device. This thus means that, since it depends on the display device, a displayed pixel does not have a fixed size.

How can it then be a unit if it doesn't have a fixed size?

> *"Simply because it's a sample of intensity from a point in space. It only exists at a point."*
>
> *(Ray Smith, 1995, p.2)*

So displayed pixels do not have a fixed size; Their size is relative to the panel's resolution, aspect ratio and size, and their intensity in a new picture depends on the intensity values of neighbor pixels when displayed with a different resolution than the captured one.

Figure 4. Parameters that determine pixel size



Source: designed by the author

Since decreasing the pixel size will decrease the picture information, thus the quality of the picture, the pixel size is of paramount importance and will be determined by the sensel size. Consequently, a higher resolution is not always offering a better image quality.

"The best resolution is the state where the number of pixels physically display matches the number of pixel drawn by the software one to one."

(Gabriel, 2014)

This means that the best resolution is the one of the signal that has not been scaled, the one of the input source such that each pixel received is mapped to a single native pixel on the display device (also called "pixel perfect image").

In other words, when the display resolution matches the capture resolution is when we get the best resolution. If that does not happen, the device can use different reconstruction filters to interpret the information such as bayer filter, cubic filter, box filter, truncated Gaussian etc.

4.1.1.2. Pixel shape

The pixel shape: Captured and displayed pixels can differ not only in terms of size but also in shape.

Shape in captured pixels: the PAR (PAR: pixel aspect ratio) describes the width of a pixel compared to the height of that pixel. The SAR is the storage aspect ratio or frame shape. This shape can vary depending on the format, PAL[xxxviii], NTSC[xxxix], etc.

[xxxviii] Phase alternating line. Is a broadcast television system for analog television used in most European countries and some of South America, Africa, Asia and Australia.

[xxxix] National Television System Committee. Is the analog television color system introduced in North America in 1954.

Grid 5. Captured pixel shape

Formats	NTSC 480i[xl]	PAL 576[xli]	HD
Pixel shape	10:11 PAR	59:54 PAR	1:1 PAR

Source: designed by the author

Shape in displayed pixels: Since displayed pixels are samples of intensity from a point in space, they have no fixed shape either. The way the display device adapts the information determines the resulting picture.

If the picture and the display do not have the same PAR, the display can incorrectly adapt the picture and the image depicted by the panel could have a different aspect ratio than the captured one.

Considering the kind of content, the changes in pixel quantity from captured to displayed will be more noticeable in contents with a specific aesthetic purpose since the process can result in an increased number of visual artifacts in the signal such as ringing[xlii] and posterization[xliii].

4.1.1.3. Image resolution

Image resolution is the amount of pixels used to form one image. To indicate this figure, we express the quantity of pixels per lines and columns that make one image as such: 1920x1080 (1920 pixels per line and 1080 pixels per column form one picture, thus 2.073.600 pixels). (Zhang and Gourley, 2009)

The most common resolutions in the industry will be described in the spatial resolution chapter.

[xl] 480 are the visible lines of the NTSC format

[xli] 576 are the visible lines of the PAL format

[xlii] This kind of artifact appears in the image as bands near the edges, they are incorrect parts of the signal that show in sharp transitions.

[xliii] This kind of artifact, also called banding, is most of the time due to an insufficient bit depth to accurately sample different color tones, the visual result in the image of this low sampling is abrupt change of color tones looking like bands in the image.

4.1.1.4. Scanning systems

The way pixels are captured or drawn in the display device it's what we call the scan system. Two different scan systems coexist nowadays: interlaced and progressive.

The interlaced system[xliv] captures or draws the lines that form the picture in alternating fashion. First the odd lines and then the even lines to draw one picture in the frame. All the odd lines are called field 1 and the even ones, field 2. To form one picture in the frame the scan system scans field 1 first and then field 2 from top to bottom and from left to right to draw each picture.

The interlaced scanning system was born in the years of old CRT TV sets since it was a great solution to reduce bandwidth required for broadcasting the video signal through the spectrum channels. It also solved flicker problems arising from the electron beam striking on the phosphor to complete the picture on the screen, when the last lines were being draw, the first ones will start to vanish. Since the fields were displayed consequently, they could create the illusion of motion due to the human persistence of vision.

The problem on the interlaced system is that it creates artifacts, especially; when displaying fast motion scenes, due to the step between the two fields that form the frame. Another problem coming from the interlaced scanning system is the overlap, commonly referred as twitter.

The progressive system[xlv] captures and draws all the lines at once. This results in a smoother looking image (R. Bull, 2014).

If a content is captured with progressive scan but needs to be broadcasted with interlaced scan the video signal will be interlaced. If afterwards the same signal needs to be displayed with progressive scan,

---

[xliv] The interlaced scanning system draws the lines that form the picture on the screen in alternating fashion, first odd lines and then even lines from left to right from top to bottom.

[xlv] The progressive scanning system draws all the lines that form the picture on the screen at the same time.

the video signal goes through a deinterlacing process, which is the process of converting interlaced video into non-interlaced video.

4.1.2. Time

In this second part we are going to review in depth what time means on a TV screen tackling two aspects: frame rate and refresh rate.

4.1.2.1. The frame rate

Since the captured and displayed frame rate can also differ, we will as well explain them separately:

Captured frame rate: is the number of different pictures captured by the camera per second (it can be captured with any scan system, progressive or interlaced). The captured frame rate is measured in frames per second (fps). This amount can vary from pioneer 14 fps, classic 24 fps for cinema and 30 fps for TV (NTSC) or 25 (PAL), until modern 48 fps, 60 fps and future 100fps or 120 fps.

These pictures can be captured with any of the two aforementioned scan methods: progressive or interlaced.

Displayed frame rate: is the number of different pictures displayed per second on an imaging display device. The displayed frame rate is measured in frames per second (fps). These pictures can be displayed with both different scan methods: progressive and interlaced.

4.1.2.2. The refresh rate

The refresh rate only exists on the display device. The refresh rate is the number of times that a display hardware updates its buffer per second. This rate includes the repeated drawing of identical pictures since the refresh rate expresses the number of times the TV picture is completely reconstructed every second. The refresh rate is measured in Hz or cycles per second.

These two rates (frame rate and refresh rate) do not necessarily coincide in amount. The refresh rate is determined by the time remanence needs of the panel. When large flat panel TV displays first appeared a problem arose, motion blur[xlvi].

A technique to enhance motion response and reduce motion blur is the backlight scanning. This technique incorporates on the TV a backlight that flashes on and off rapidly adding extra Hz every second (in between the screen refresh rate repeated frames).

> *"The more times the screen is "refreshed" every second, the smoother the image is in terms of motion rendering and flicker reduction."*
>
> *(Silva, 2018)*

Since the refresh rate of the screen is generally higher than the original frame rate of the footage, all different pictures are displayed more than once. To display 24 frames per second on a TV with a 120Hz refresh rate, each different picture is repeated 5 times every 24th of a second.

> *"You can't add detail beyond what is already in the source footage."*
>
> *(Greenwald, 2013)*

This means that all the technologies to enhance motion response have not been created to add information to the picture but rather for two different reasons: (1) to convert the footage for it to be able to be displayed

[xlvi] Apparent streaking of moving objects across the screen.

on a specific screen and (2) to solve the screen's motion response and motion blur problems. To summarize, panels have their own screen refresh capabilities, which modify the frame rate but not the contents of each individual picture.

What does modify the contents of each individual picture? Mainly the 2:3 pulldown, the frame (or motion) interpolation and BFI.

4.1.2.2.1. 2:3 Pulldown

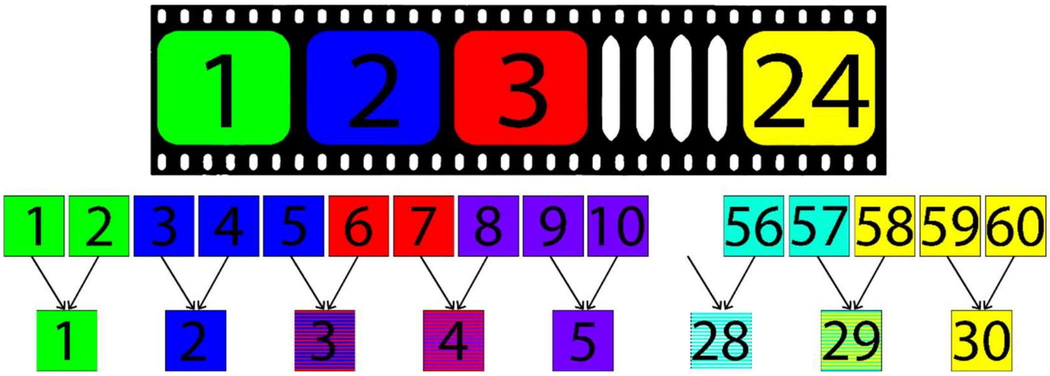
> *"Film is generally shot and projected at 24 frames per second (fps), so when film frames are converted to NTSC video, the rate must be modified to play at 29.97 fps. During the telecine process, twelve (12) fields are added to each 24 frames of film (12 fields = 6 frames) so the same images that made up 24 frames of film then comprise 30 frames of video."*
>
> *(Stewart, 2008)*

What the 2:3 pulldown does is adapt the standard film frame rate (24fps) to the NTSC standard frame rate (30fps) as follows;

The first frame is formed by two fields, the second frame is formed by three fields, the third is formed by two fields again, the forth is formed by three fields and so on.

After this separation of the frames, the final frames are created as follows:

Figure 5. 2:3 Pulldown



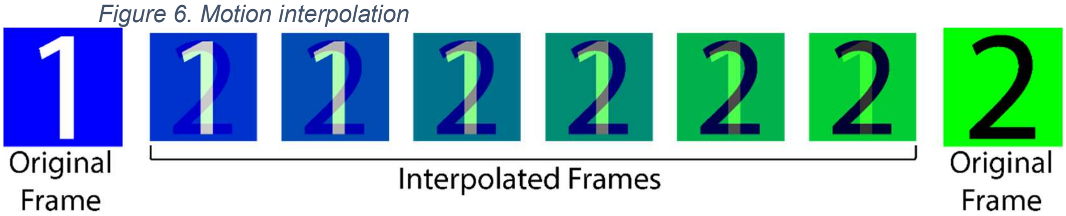
Source: designed by the author

By using this technique, the resulting amount of frames per second is 30 instead of 24 which is what the NTSC standard needs to broadcast.

4.1.2.2.2. Frame or motion interpolation

Frame or motion interpolation: is a form of video processing in which intermediate animation pictures are generated between existing ones by means of interpolation adapted on the object movement between correlative frames, in an attempt to make animation more fluid and to compensate for display motion blur.

Figure 6. Motion interpolation



Source: designed by the author

Nowadays most flat panel TV displays have a refresh rate of at least 60 Hz per second (Some 100 Hz, 200 Hz); This has made the manufacturers design tools for the display device to use those extra frames the panel has for remanence needs to smooth the motion tracking. Each brand has a different name for it (*Motionflow,* SONY*; Automotion plus,* SAMSUNG*; Trumotion,* LG,ClearFrame Toshiba, ClearMotion Drive JVC …) but they all pursue the same objective: make movement appear smoother by inserting more motion-based interpolated frames between the original ones (Porter, 2017).

> *"These new pictures are made by combining and processing the data of the pictures surrounding them, generating the pictures the HDTV thinks it should draw between the pictures it's told to draw by the media. You're looking at more individual pictures as the screen draws them, but these pictures weren't on the Blu-ray disc or television signal that the screen is receiving; the HDTV is generating those additional pictures itself."*
>
> *(Greenwald, 2013)*

This means again that all these technological attempts to make motion more fluid and reduce motion blur are not designed to add any information to the picture but to solve the aforementioned problems (motion blur, remanence needs).

When taking into account the kind of content, the changes in frame quantity from captured and displayed will be more noticeable in contents with a specific aesthetic purpose too. This technology works very well for sports where it can be a struggle to keep track of a fast-moving ball, but it's not as good for films, where the extra frames make everything look fake and unnatural. This effect on fiction content has earned its own name, the "soap opera[xlvii]" effect.

4.1.2.2.3. The black frame insertion (BFI)

The black frame insertion or scanning backlight consists on inserting "black frames" instead of creating brand new frames out of interpolation. This process is done by turning off part of the backlight of the panel. Since the image is not holding in place, the brain will not automatically blur it to get the next position. If this process is done poorly, the image flicker will be easily noticed.

4.1.3. Amount of visual information

In this last part we are going to review in depth what determines the amount of visual information of a picture tackling two aspects: Color and contrast.

4.1.3.1. Color

When talking about color we need to describe two different concepts, color depth or bit depth and color space or human visible spectrum.

Before addressing those concepts, we will define the model of the color video signal, the RGB (Red Green Blue). Is an additive color system in which those three additive primary colors are put together in different manners to create a wide range of colors.

In the RGB model, the three color components are added together to make the final color, for example; adding red to blue to get magenta, adding blue to green to get cyan, adding green to red to get yellow, adding all three additive primary colors to get white.

[xlvii] Side effect resulting from watching fiction contents with the motion interpolation tool on that gives a new look to the contents where everything seems to be recorded on video instead of film.

4.1.3.1.1. Bit depth

The bit depth indicates the number of bits used for each color component of a single pixel. Thus, pixels are samples of intensity described in integer numbers indicating brightness and color. But captured bit depth and displayed bit depth can also vary; we will again explain them separately.

Captured bit depth: refers to the amount of information bits used by the camera to describe each pixel.

"An image is a rectilinear array of point samples. For a color picture a pixel might actually contain three samples, one for each primary color contributing to the picture at the sampling point."

(Ray Smith, 1995)

Thus, the bit depth of a pixel is nothing but the number of bits of information used to indicate each color component of a pixel, RGB or bps[xlviii].

"A "map" of locations and values of pixels is called a bitmap. Any bitmap image can be represented by giving the locations and values of all its pixels."

(Goldman, 2007)

The more bits used to indicate the color the more shades of grey are shown and less color banding problems arise. But that color will always be within a specific range of colors, the gamut, and a digital code value will locate it within the specific color space.

[xlviii] Bits per sample

"A bitmap image takes the form of an array where the value of each element (pixel) corresponds to the color of that portion of the image."

(Kolås, 2007)

An image with 8 bit per color component can show 256 different shades, the total amount of bits of color information of that image would be 24 and the possible color combinations more than 16 million.

Displayed bit depth: refers to the amount of information bits displayed by the device to describe each pixel. This amount will depend on the panel capability.

Nowadays there are two main options; panels with 8 bit per color component or panels with 10 bit per color component.

4.1.3.1.2. Color space

We will now give some more specific information of what a color space is. A color space is a specific organization of colors that relates colors to numbers in a three-dimensional form (X,Y and Z) that can form all possible color combinations within the gamut.

When moving across a color space each direction is a color aspect; It thus makes it possible to reproduce representations of color by specifying brightness, saturation and hue.

The wider the gamut, the wider the color combination options and the wider the amount of color representations.

The different ITU[xlix] recommendations throughout the years have been increasing the color space so that more and more combinations would be possible.

The CIE 1931 is a color space that delimits the colors that can be perceived by human vision; the ones within the visible spectrum.

The ITU's main products are recommendations, standards defining how telecommunication networks should work.

In 1990, the ITU-R recommendation BT.709 (*itu.int*, 1990) was approved to standardize the format for high definition television with a 16:9 aspect ratio.

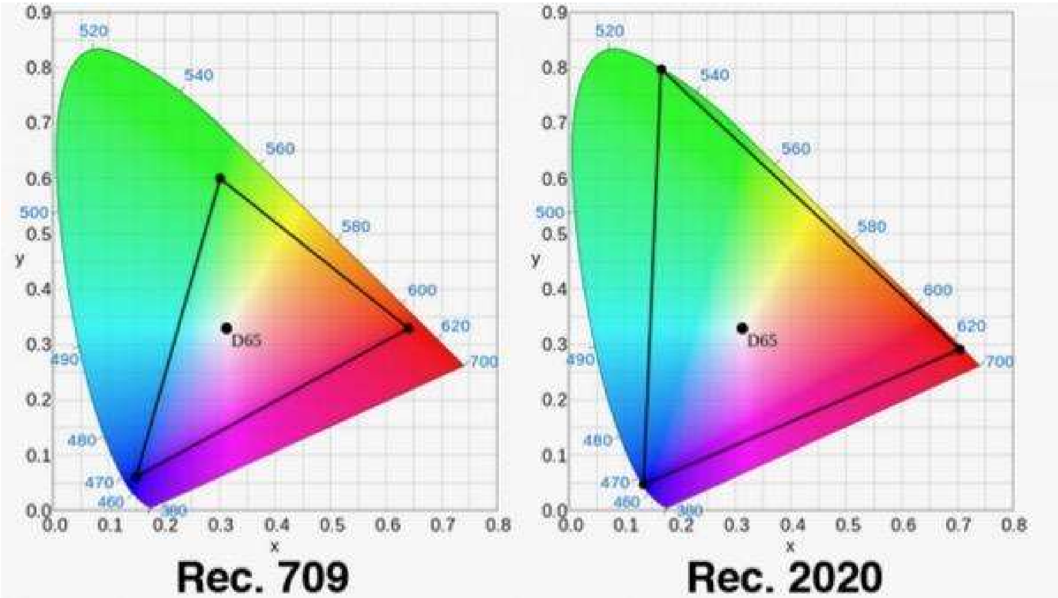
The color space recommended as a standard in BT.709 covers 35,9% of chromaticities of the CIE 1931 color space chromaticity diagram[l].

In 2012, the ITU-R recommendation BT.2020 (*itu.int*, 2012) was approved to standardize the format for ultra-high definition television. The color space recommended as a standard in BT.2020 covers 75,8% of chromaticities of the CIE 1931.

[xlix] International Telecommunication Union, founded in 1865. The ITU-R are the recommendations that the ITU has been launching throughout the years in terms of image quality and regulations for standards.

[l] See figure 2.

Figure 7. CIE 1931 chromaticity diagram showing the Rec. 709 and 2020 color space differences.



Source: Sound&Vision

Captured color space

The color space on the capture process depends on the color space of the camera. A camera can record contents using the BT.2020 color space but later, these contents can be broadcasted by adding a BT.709, thus reducing the color gamut and changing the color hue of the original footage.

Displayed color space

The displayed color space will adjust to the color space of the display, shrinking the signal if it has a wider color space than the panel and thus displaying different colors or not using the entire gamut if the panel's space is wider than the signal's.

4.1.3.2. Contrast

The contrast is a property defined as the luminance ratio of the brightest part of the signal to that of the darkest one that the system is capable of producing.

Here again we find differences between captured contrast and displayed contrast. When talking about the captured contrast we are referring to the dynamic range[li] of the camera.

Captured dynamic range

The dynamic range of a camera would be the difference between the lightest (white) and the darkest (black) usable signal that the sensor is able to capture at once. In cinema and photography, it is measured with f-stops. The larger the dynamic range the camera has, the more different brightness values it is able to capture at once. (Petersen, 2016)

Displayed dynamic range

When talking about the displayed contrast we call it the contrast ratio. That ratio refers to the difference in the amount of light between the darkest black and the lightest white on the screen. Of course, when evaluating the displayed contrast ratio, we need to consider the lighting conditions of the room, since those will affect the human perception.

We express the contrast ratio of a panel comparing the brightest white and the darkest dark as such; 100:1 where 100 is the brightest signal and 1 the darkest. Thus, 100:1 is the difference in luminance that the panel can display at once.

The display contrast ratio can be native or dynamic. The native contrast ratio is what the display technology is able to do in terms of contrast. If it is native and the content has more dynamic range than the panel, some parts of the range will not appear on the displayed image. If instead the contrast ratio of the panel is higher, it will not use all its range possibilities.

[li] The difference between the darkest black and the lightest white of an image, the larger the dynamic range, the more different brightness values the image has. We can measure the dynamic range in f-stops on a camera or in contrast ratio such as 100:1 (100 being the white and 1 the black) on a panel or projector.

When the contrast ratio is dynamic, the technology of the panel augments its native contrast ratio. To increase it, it senses what content it is showing and adjusts the overall light output accordingly. With a dark image, the panel turns down the backlight so the resulting image will appear darker. It does this at the expense of the bright areas of the screen, which also become darker. With a bright image, the panel turns up the total light output, so the resulting image appears brighter. It does this at the expense of the darker areas of the screen, which will become brighter too.

A display with a native high contrast ratio will thus always give a better image performance than a dynamic one (Morrison, 2011). The kind of content that will be more affected by those changes in color and contrast will again be those with an aesthetic purpose since the chrominance and luminance can be modified from the original footage once displayed on the screen.

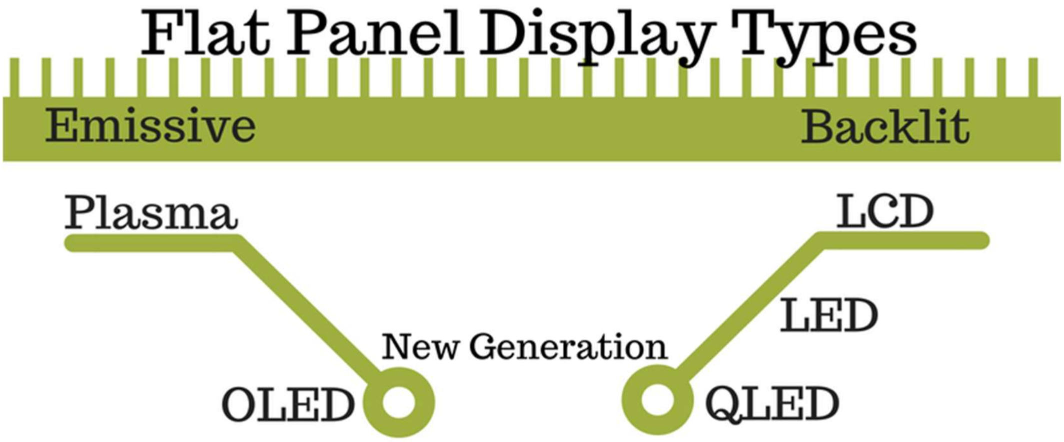
The current standard recommendation launched by the ITU for HDR broadcast is the BT.2100 (*itu.int*, 2018). This recommendation establishes the broadcasting parameters for HDR content.

5. Types of Flat Panel TV Displays: Plasma, LCD, LED, OLED and QLED

5. Types of Flat Panel TV Displays: Plasma, LCD, LED, OLED and QLED

We can broadly classify flat panel TV displays as emissive or backlit as follows;

Figure 8. Flat panel TV display types



Source: designed by the author

As figure 8 shows a very important feature that will differentiate the different flat panel TV display technologies is where the light is produced: in emissive flat panel TV displays the light is produced directly on the screen. However in backlit flat panel TV displays the light is produced behind the screen and by filtering this light coming from the back of the panel, the image is formed (Hübner and Dierkes, 2010).

Plasma and OLED technologies belong to the emissive group and LCD, LED and QLED are part of the backlit one.

Both Plasma and LCD are now considered as old technologies and Plasma is actually no longer available in the market since 2016. LCD is still in the market but only with LED light (the first LCD flat panel displays were lit with fluorescent light) and the newest technologies are OLED (2013) and QLED (2017).

As the terms OLED and QLED only specify where the light is produced, we will briefly go through the different technologies of these panels.

5.1. Characteristics and differences

The main difference here will be what a Plasma display panel is and what an LCD is. As for LED and LCD, they are just LCD panels that use a LED lamp instead of a fluorescent one. So, they are not different technologies, they just use different kinds of light sources.

Let's then talk about Plasma and LCD panels.

> *"The main difference between Plasma and LCD technologies is that LCD pixels don't emit any light. All the qualities but also all the faults of the technology stem from that key characteristic."*
>
> *(Dupont, 2005)*

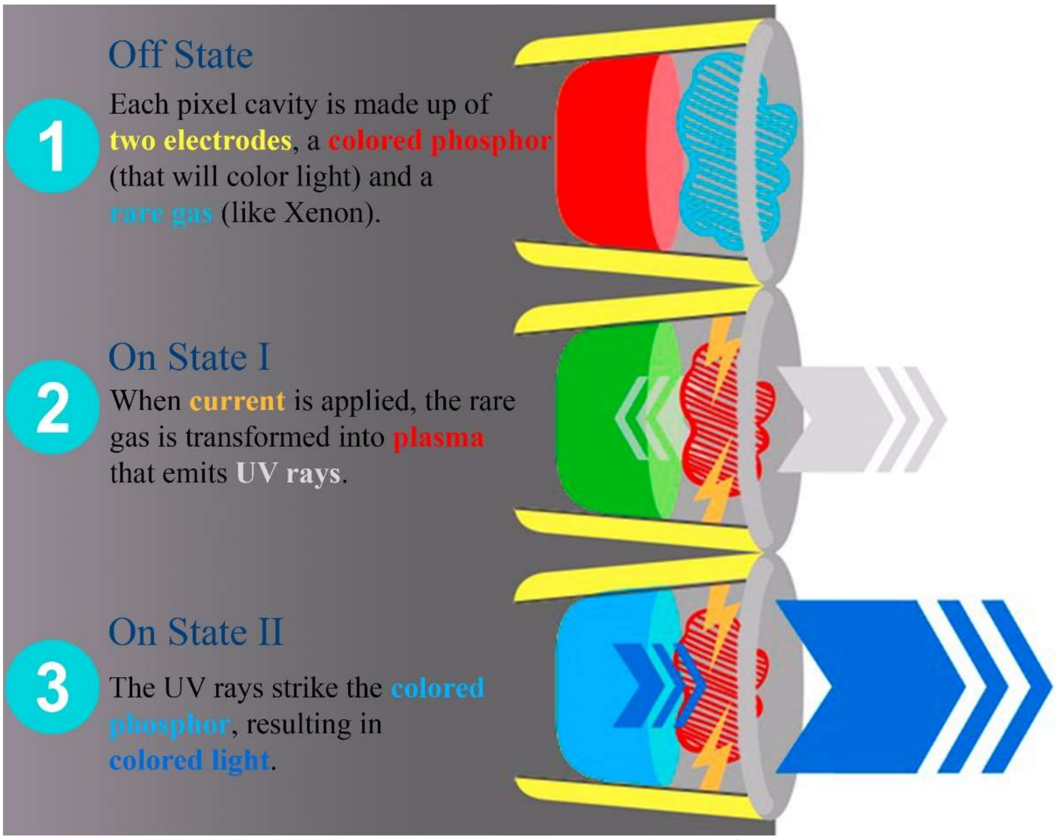
5.1.1. The plasma display panel

The plasma display panel's (PDP) technology is broadly a rare gas trapped between two pieces of glass that, after being excited by the current is transformed into plasma gas (Hartwig, 1990).

Thanks to the nature of plasma gas (made up of both free electrons and positive ions), the impact between atoms creates photons or, in more common words, light. Nevertheless, this light belongs to the ultraviolet range of frequencies and is thus not visible to humans. In order to transform this light into visible light, the walls of the tube are coated with phosphor, which transforms one radiation form into another.

Each pixel is made of three different cavities containing a rare gas each. Each cavity has an electron at the front and one at the rear. When excited by the alternating current, the electrons will transform the rare gas into plasma that will be set in motion and start emitting UV rays that, after striking the phosphor will appear as red, green or blue colored light and as such will be perceived by the viewer after passing through the glass (Dupont, 2005).

Figure 9. Plasma panel structure



Source: designed by the author

5.1.2. The LCD display panel

The LCD display screen can use two different technologies: the passive or the active matrix. Nowadays almost all LCD displays use an active matrix since it's a superior technology (also called thin film transistor, TFT) (Rouse, 2010).

The structure of an LCD works as follows: A source of light (fluorescent or LED) emits light at the back of the device, the beam of light passes through the rear polarize filter (let's imagine a horizontally oriented polarizer) and reaches the TFT matrix where the liquid crystals are; Then it passes through the color filter and finally the front polarizer (let's imagine a vertically oriented polarizer) before it reaches the viewer.

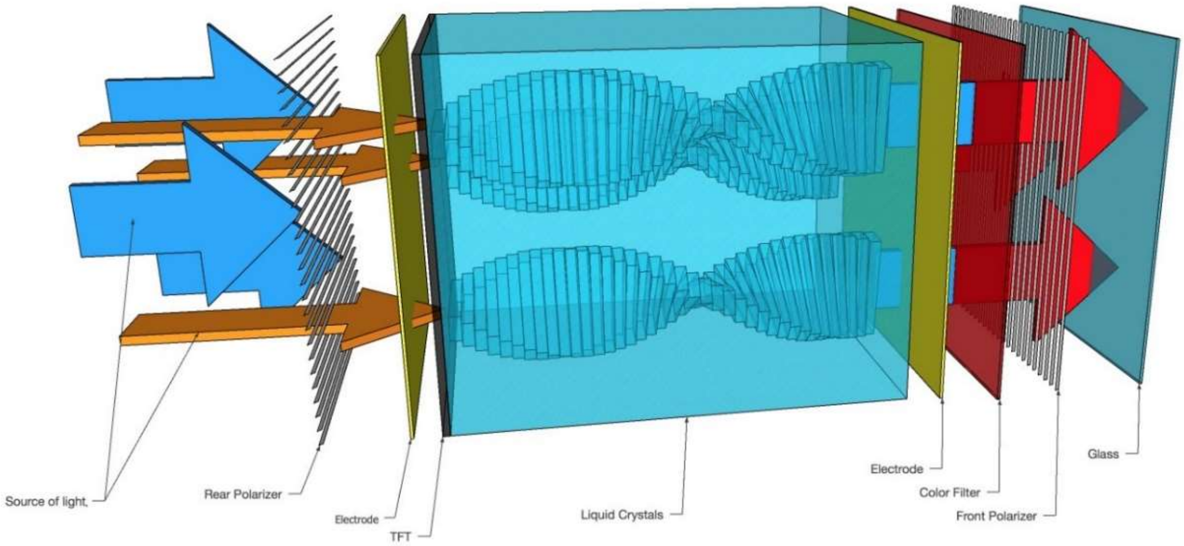
You are probably wondering why two polarizers? Wouldn't this tend to block out light?

Well, that would be the case if it were not for the special properties of liquid crystals. Liquid crystals have the property of turning the plane of polarization of the light to align with the second polarizer and the light can then pass through.

But if we apply a current at each end of the TFT, the crystals will prevent light from passing through the second polarizer and thus light will be blocked.

And by varying the voltage at the two ends, the TFT can produce intermediate states (Dupont, 2005).

Figure 10. LCD panel structure



Source: designed by the author

By seeing the structure of the LCD in figure 10 it is easy to understand why this technology has poor black levels: the polarizer's performance is never perfect, it cannot always block all the light rays and thus LCDs are not as good as other technologies in generating good black levels.

However, this technology does not suffer from image burn-in. The image burn-in phenomenon is the result of leaving an image stationary for long periods of time on panels with phosphor compounds. The phosphor compounds will react to this situation as does fabric left for long periods of time exposed to sunlight and will thus vary its color as a result from the image burn-in. (*en-touch*, 2015)

5.1.3. The LED display panel

As mentioned before, LED displays are just LCD technology that uses LED lamps as a source of light instead of a fluorescent one (Hesse, 2017).

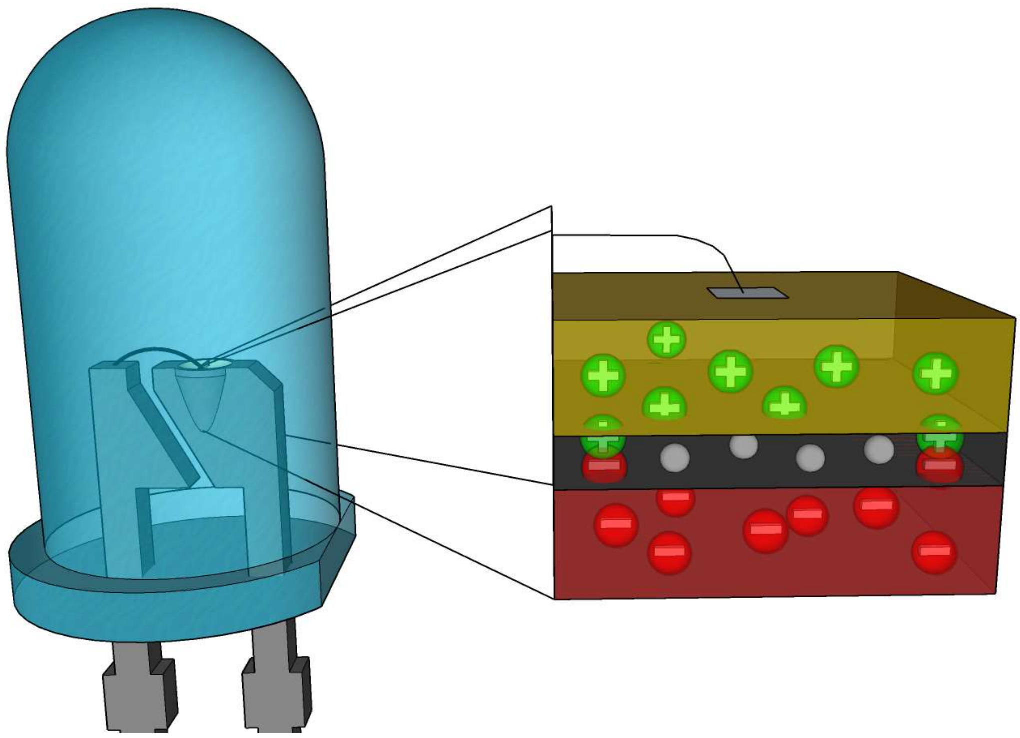
But, what's a LED?

LED stands for light-emitting diode. A light-emitting diode is nothing but a solid semiconductor material (like gallium arsenide, gallium phosphide, gallium nitride, …) that will produce light when current passes through it.

So, broadly, a LED works as follows: the semiconductor material has two bands where the holes (the band that is poor in electrons or p-type) and electrons (the band that is rich in electrons or n-type) are. When we apply current to the semiconductor material it will flow in one direction only (called a junction diode). When both gather as the electrons cross the active region between them, they produce photons.

The separation of the bands will determine the energy of those photons and the energy of the photons will determine the color of the light. Hence, by controlling the movement of the electrons we will be able to control the light produced by the LED (Tang and VanSlyke, 1987).

Figure 11. LED structure.



Source: designed by the author

LED display panels can be of two forms: LED back-lighting and edge lighting.

The LED back lighting is an array of LEDs placed at the back of the LCD screen and the LEDs can be lit or dimmed by zones in a process called local dimming.

The LED edge lighting means that the screen has LEDs placed along its edges. They can be placed just at the bottom, bottom and top, left and right or on the four edges.

The pros and cons of the two are very simple: edge lighting allows manufacturers to design thinner screens whereas back-lighting results in a better picture quality (Hesse, 2017).

LED technology has problems producing LEDs in the green-yellow color range, unfortunately, the part of the visible spectrum towards which the human eye has the highest sensitivity (Muccini and Toffanin, 2016).

5.1.4. The OLED display panel

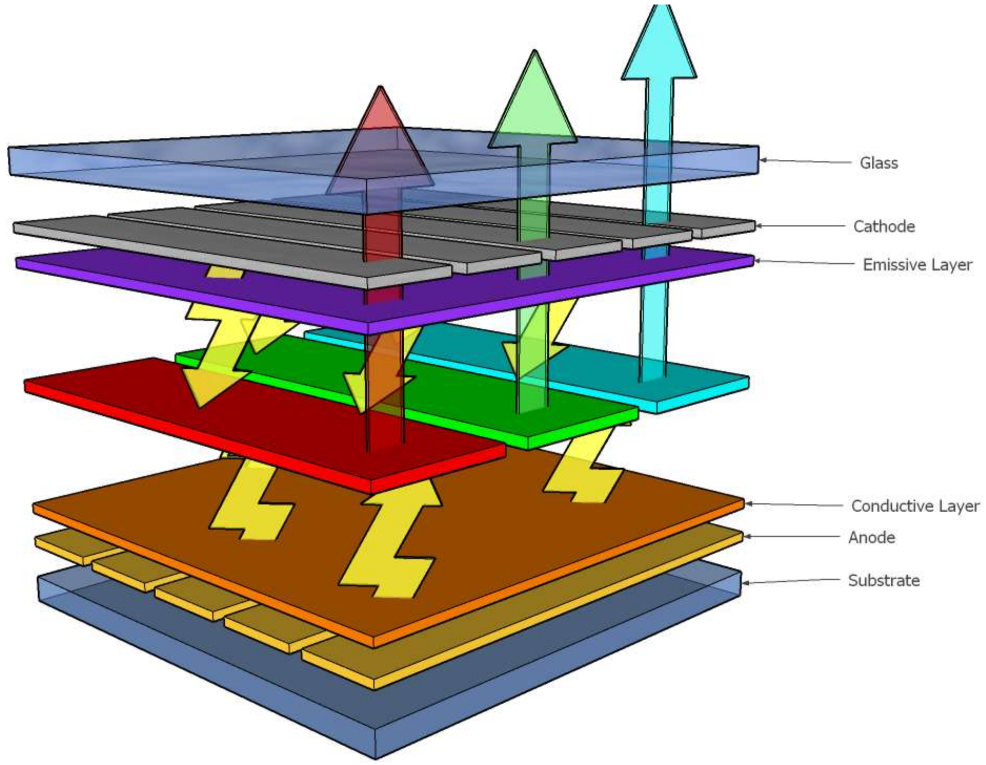
OLED stands for organic light-emitting diode. Which means that instead of the materials used on a LED, it uses organic molecules in order to produce light.

These organic molecules can come from oligomers, polymers, organometallic species. They just need a high efficiency emission process; fluorescence or phosphorescence.

OLED display's structure is simple and made up of six different layers; the substrate at the bottom (usually made of glass or plastic), the anode or positive terminal, the conductive layer (made of organic molecules), the emissive layer (also made of organic molecules), the cathode or negative terminal and, at the top, the seal (usually made of glass or plastic).

When current is applied, electrons enter the cathode and holes in the anode then electrons reach the emissive layer and holes the conductive layer. When holes and electrons meet each other in a process called recombination, they produce photons. By adding a color filter between the cathode and the seal, we can produce colored light (Tang & VanSlyke, 1987). If more current is applied, the brighter the light appears (Karzazi, 2014).

Figure 12. OLED structure.



Source: designed by the author

The lack of permanence of backlight allows OLED technology to reach a higher contrast ratio and specially, better black levels.

OLEDs also have a high color quality since each color is obtained by the combination of RGB[lii] but it is superior in the range of green. The

[lii] Red Green Blue. Is an additive color system in which those three colors are put together in different manners to create a wide range of colors.

challenge this technology would have to face in terms of color production is the development of a deeper, more efficient and stable blue (Muccini and Toffanin, 2016).

OLED technology has outstanding wide angles, some panels nearing 90 degrees off center without the color or clarity losses common in LEDs (Tarantola, 2014).

The main challenge the OLED technology will have to face is lifespan.

> *“The optimum thickness for the lifetime does not correspond to the optimum structure for the luminance and efficiency.”*
>
> *(Muccini & Toffanin, 2016, p.269)*

5.1.5. The QLED display panel

QLED stands for “Quantum dots light emitting diode” so, let’s first establish what a quantum dot is.

A quantum dot is an incredibly small semiconductor particle with a specific property; when current is applied to it, it produces light of a different color depending on its size. This means that, depending on the quantum dot’s size, the color that it emits will differ (Vandervell, 2016).

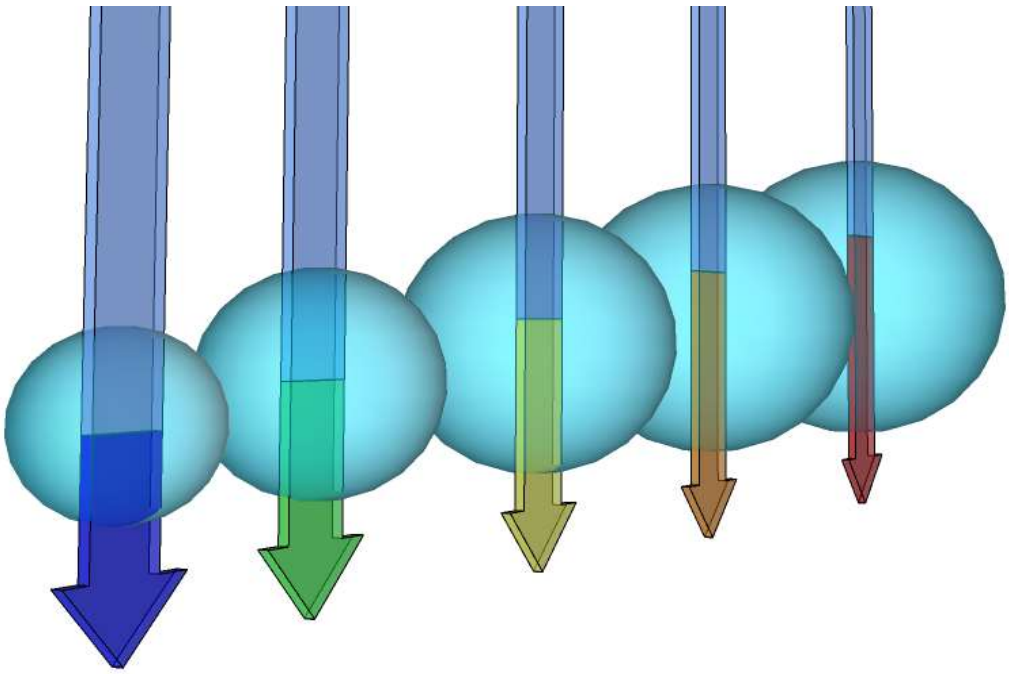
What is the advantage of this?

> *“The advantage of this is that they’re capable of emitting brighter, more vibrant, and more diverse colors, the sort of colors that really make HDR content shine, thanks to the high peak brightness that can be achieved.”*
>
> *(Laird and Mundy, 2017)*

The higher peak brightness that quantum dot technology provides opens the possibility to support new technologies such as the high dynamic range[liii]. Its higher color saturation means that quantum dots can increase the color gamut on an LCD screen by up to 40 to 50 per cent. This puts quantum dots on the path to reach the BT2020[liv] color space. The improvement in color accuracy is also remarkable, since its related to their size, it makes it possible to tune very precisely the kind of light needed (resulting in a specific color) (Vandervell, 2016).

The main difference between the QLED and OLED technologies is what was established in figure 8: the lighting. One is backlit and the other is emissive. As explained in the LED section, this means that QLED technology cannot reach black areas as does OLED since it works with the local dimming process. Since you can turn the pixels off on an OLED screen, there would be no light bleed and this will thus result in a purest black (Hall and Grabham, 2018).

Figure 13. Quantum dot structure.



Source: designed by the author

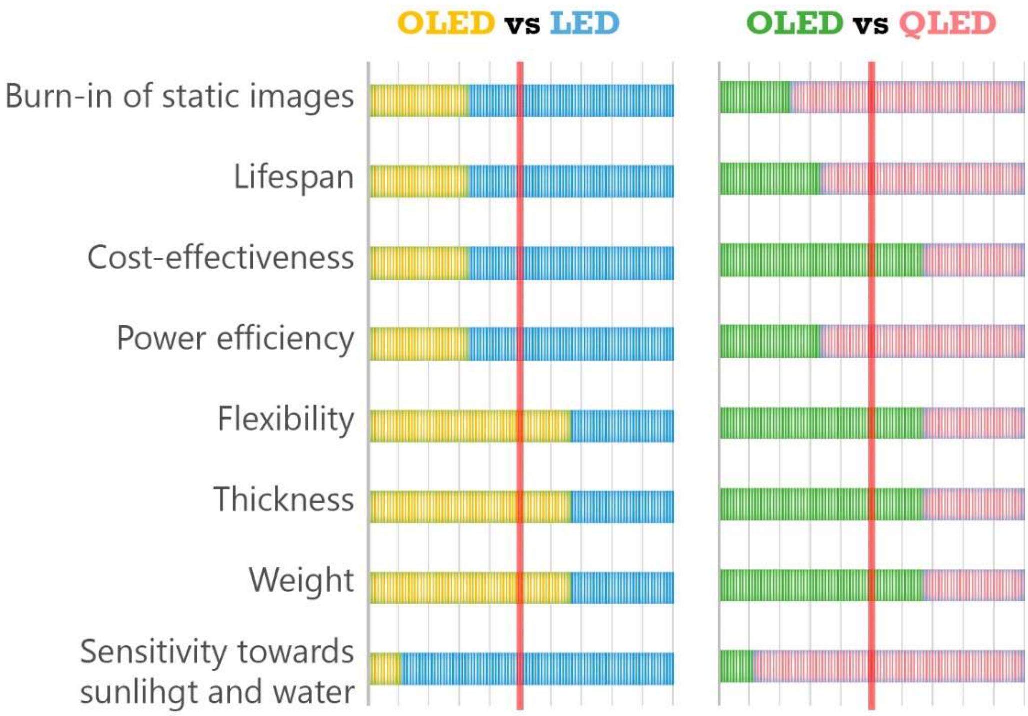
[liii] High Dynamic Range. An HDR image has around 17 f-stops of dynamic range.
[liv] Standard recommendations from ITU for UHD TV broadcast.

5.2. Technology comparison: Usability features and image quality features

After seeing the characteristics and differences between each of the technologies, we are going to broadly compare the technologies in the market according to their general usability features.

This implies that we will no longer analyze the Plasma display since it is no longer on the market.

Figure 14. Usability features of current flat panel TV display technologies. (Silva, 2018) (Dupont, 2005) (Bagher, 2017)(Tang and VanSlyke, 1987).



Source: designed by the author

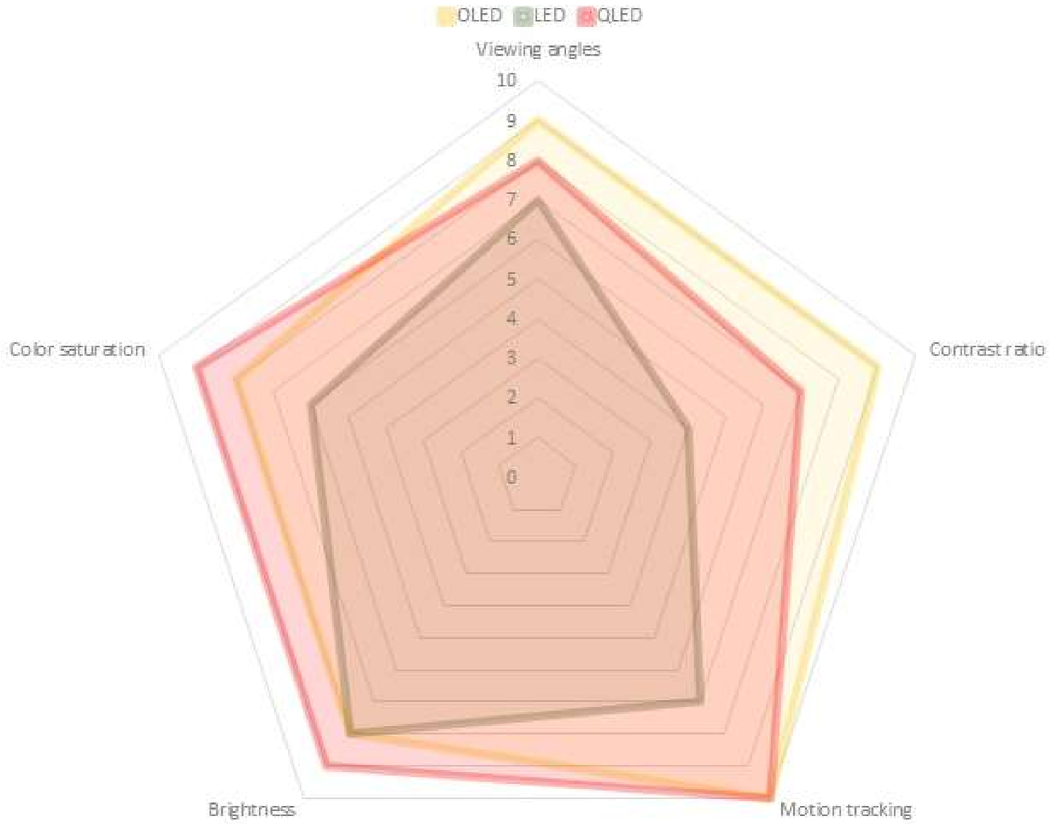
After having a look at figure 14, we can conclude that OLED technology still has a lot of room for improvement when it comes to usability features. It's weight, thickness and flexibility are the only positive usability features of the technology when compared with the rest of the technologies on the market.

As for QLED, it will have to improve its cost-effectiveness in order to reach a broader market.

LED technology is clearly the best in the market when it comes to its usability features.

Let us now take a different approach when comparing the different technologies on the market. The following figure will expose their image quality features.

Figure 15. Image quality features of current flat panel technologies. (Avila and Bailey, 2015).



Source: designed by the author

An absolutely different figure shows up when comparing the technologies according to their image quality figures: OLED is the winner in this field and LED shows the poorest performance. QLED stays in second position, closer to OLED than to LED which stays way behind the other two technologies.

6. Broadcast Formats

6. Broadcast Formats

In order to better understand the final result of the image quality on a flat panel TV display, we are going to review all the different steps the image goes through before reaching the display device and consequently, the final user.

The main steps are three different processes: capture process, broadcast process and display process. This will not apply obviously to contents watched from a storage device like a Blu-ray, DVD or similar. When going through these steps, the different parameters that affect the image quality are modified to adapt the image to the needs of the different media (the camera, the TV signal and the TV display device) resulting in the final image quality.

As we mentioned already in the introduction and theoretical framework, the parameters that affect the image quality and that will need to be modified in order to adapt the image to the different media are:

- Resolution (SD, HD, UHD, …)
- Scanning system (progressive or interlaced)
- Bit depth (8 bit, 10 bit, 12 bit, 14 bit, …)
- Color space (BT.601, BT.709 -covers 35,9% of the spectrum-, BT.2020 -covers 75,8% of the spectrum)
- Contrast (100:1, 5000:1, …)
- Frame rate (24 fps, 25 fps, 30 fps, 48 fps, …)
- Refresh rate (60 Hz, 120Hz, 240Hz, …)

6.1. Characteristics

To give a simple example, the path of a content from camera to display device could be as follows;

1. Recorded on camera with the following parameters: HD, progressive scan, 10 bit, BT.709 color space, 5000:1 and 24 fps.
2. Then broadcasted SD[lv], interlaced scan, 8 bit, BT.601 color space, 300:1 and 24 fps.
3. And in the end displayed on a UHD flat panel, with progressive scan, 10 bit, BT.709 color space, 5000:1, 24 fps and 240 Hz.

To picture another scenario, here is another example of this path;

The main characteristics in technical terms of a current cinema camera in the market: **Arri Alexa LF(I)**

- Resolution: 4K
- Scanning system: Progressive
- Bit depth: 14 bit
- Color space: Log C
- Contrast: HDR
- Frame rate: 150fps
- Refresh rate: (this process is not happening during capture)

The main characteristics in technical terms of the current standard format, **BT.709** (*itu.int*, 1990), for broadcasting on HD TV are as follows:

- Resolution 1920x1080 pixels
- Scanning system: interlaced or progressive
- Bit depth: 8 bit
- Color space: BT.709, covers 35,9% of the spectrum
- Contrast: SDR[lvi]
- Frame rate: 25 fps, 50 fps and 60 fps
- Refresh rate: (this process is not happening during broadcasting)

[lv] Standard Definition. TV format that defines the spatial resolution of the images that compose the video sequence in analog formats. In Europe, the PAL system establishes a resolution of 576 lines and 720 pixels per line. In USA, the NTSC system establishes a resolution of 480 lines and 720 pixels per lines. Both formats use interlaced scan.

[lvi] Standard Dynamic Range. An SDR image has around 6 f-stops of dynamic range.

The main characteristics in technical terms of a current flat panel TV display in the market: **Samsung flat panel TV display UE65LS03NAU**

- Resolution: 4K
- Scanning system: progressive
- Bit depth: 10 bit
- Color space: between BT.709 and BT.2020
- Contrast: HDR
- Frame rate: 25 fps, 50 fps and 60 fps
- Refresh rate: 240 Hz

To add another viewing option let us see what the differences could be by watching the contents on linear TV or on Netflix.

Figure 16. Parameters comparison from capture to display

	Arri Alexa	Netflix	TV BT. 709	Samsung TV
Resolution	4K	HD / 4K	1920x1080pixels	4K
Scaning System	Progessive	Progessive	Interlaced / Progessive	Progessive
Bit Depth	14bit	8bit	8bit	10bit
Color Space	Log C	BT. 709 / BT. 2020	BT. 709	BT. 709 / BT. 2020
Contrast	HDR	SDR / HDR	SDR	HDR
Frame Rate	< 150fps	< 120fps	25, 50 and 60 fps	25, 50 and 60 fps

Source: designed by the author

As we can see there are great differences between the parameters of the capture system and those of the broadcasting system and from the broadcasting to the display.

There are two deterioration types that the signal undergoes from its capture at the source until it is sent to the display device;

Encoding: this implies loss of quality due to bandwidth availability and network features.

Processing of the signal: this implies loss of quality due to the different processes the signal goes through (chrominance subsampling, scaling, …).

After that point, the signal gets to the display device through the different options such as DTTV (Digital terrestrial TV), Satellite digital TV, Digital cable TV, IPTV (Internet Protocol TV), Mobile TV.

We can also see that there are great differences between the parameters of the broadcasting system and those from the display device. This results in a deterioration of the image quality.

If the display format and signal input format differ, the display applies a format conversion. The problem is that this process does not aim for the best picture quality but for the best performance of the display system.

This format conversion deals with resolution (adapting the signal resolution to the display panel resolution), frame rate (adapting the refresh rate to the display panel's needs), color space, bit depth, scanning system, etc (Klompenhouwer, 2006).

6.2. Practical example: Resolution adaptation

Half of the TV display devices in the market nowadays are 4K devices; However almost all cable, satellite, streaming, blu-ray, etc content is HD. If the display device does not upscale[lvii] the content, it would take up a quarter of the screen (Carter, 2018).

Thus, all display panel devices apply a scaling system in order to adapt the content to the panel. Does this process imply quality loss? Yes.

[lvii] Is a form of video processing in which by using an interpolation algorithm, the panel adapts the amount of pixels of the contents to its native resolution.

As we mentioned in the theoretical framework, "The best resolution is the state where the number of pixels physically displayed matches the number of pixels drawn by the software one to one."

(Gabriel, 2014)

However, the perception of this quality loss by the viewer can be reduced depending on the quality of the scaling system.

The scaling process involves a lot of steps. The first one is to determine which kind of signal the TV display panel device is receiving (resolution, type, etc), the second is noise reduction, then edges analysis (Carter, 2018).

One of the most striking quality losses could be detail loss which depends on the sharpness of the edges of subjects and objects in the picture, thus, one of the tasks of the scaling system is to determine which parts of the picture are edges and figure out how to make them finer (Morrison, 2015a).

The last steps are textures and details. It compares how different elements of that picture should look to get a more accurate result.

It doesn't look at the pixel in isolation, but also at the pixels around it, diagonal and pixels across multiple frames to get a consistency in the picture quality (Carter, 2018).

This is only an example on what happens with resolution, but similar processes take place with other parameters like the scanning system, color space, etc.

"There are four ways to deinterlace an image; all of which reduce image quality" (Jordan, 2015).

6.3. Differences depending on the content source

After carrying out our fieldwork, we realized that, due to this adaptation to the panel, the viewer can sometimes perceive a great quality loss.

But we realized that the quality loss perception was different depending on the nature of the content and not only depending on the device technology. That led us to think that some contents are more exposed in terms of quality loss perception because of their nature than others.

We will thus expose in the following chapters the differences we found during the analysis of the results of our fieldwork as follows;

Motion interpolation on and off with sport contents and cinematographic contents in both QLED and OLED technologies.

Scaling system on and off with sport contents and cinematographic contents in both QLED and OLED technologies.

HDR effect on and off with TV contents and cinematographic contents in both QLED and OLED technologies.

Modes on and off with sport contents and cinematographic contents in both QLED and OLED technologies.

The current standard format for broadcasting on HD TV is the ITU-R Recommendation BT.709. This standardizes the high definition television format with 16:9 aspect ratio. This standard was approved in 1990.

The UHD standard for broadcasting for TV is the ITU-R Recommendation **BT.2020** (*itu.int*, 2012). It should be noted that this standard was approved in 2012; two further editions have been published since then.

- Resolution:3840x2160 pixels (4K, UHD) and 7680x4320 pixels (8K)
- Scanning system: progressive

- Bit depth: 10 bit or 12 bit
- Color space: BT.2020, covers 75,8% of the spectrum
- Contrast: SDR
- Frame rate: 120p, 119.88p, 100p, 60p, 59.94p, 50p, 30p, 29.97p, 25p, 24p, 23.976p
- Refresh rate: (this process does not happen during broadcasting)

As we can see, this standard is a lot closer in its parameters to those that we nowadays have on cameras and TV display devices on the market.

It leads us to think that it would mean a great improvement in terms of image quality since it equals the image quality parameters all along the signal path.

The newest standard is the ITU-R Recommendation **BT. 2100** (*itu.int*, 2018) that standardizes the various aspects of high dynamic range (HDR) and was approved in 2018.

- Resolution: 1920x1080 pixels (Full HD[lviii]), 3840x2160 pixels (4K, UHD) and 7680x4320 pixels (8K)
- Scanning system: progressive
- Bit depth: 10 bit or 12 bit
- Color space: Same color space as BT.2020, covers 75,8% of the spectrum
- Contrast: HDR (HLG[lix]/PQ[lx])
- Frame rate: 120p, 119.88p, 100p, 60p, 59.94p, 50p, 30p, 29.97p, 25p, 24p, 23.976p

[lviii] Full High Definition. TV format that defines the spatial resolution of images such as 1080p which means 1080 lines and 1920 pixels per line with progressive scan.

[lix] Hybrid Log-Gamma. A gamma curve compatible with SDR.

[lx] Perceptual Quantization. The format of HDR 10 and Dolby Vision.

7. Spatial Resolution: HD Ready, Full HD, 4k, 8k

7. Spatial Resolution: HD Ready, Full HD, 4k, 8k

In the following chapters: Spatial resolution, temporal resolution, bit depth and color space and dynamic range, we will expose the results from our fieldwork.

We will first explain the technical aspects of the parameter we were testing, then we will expose the results of our consumer panel, and then those of the focus group for each one of the sections.

Afterwards we will summarize the results from each specific tool test that will lead us to the final conclusions at the end of the research.

As explained in the methodology section, this consumer panel was carried out with a random sample of 45 people and our focus group was carried out by six professionals (from the flat panel industry and cinematography) coordinated by an expert (image engineer).

All the graphics appearing in the following chapters are based on the data we were able to collect from the survey made by the members of the consumer panel and is exclusive information from this research as are the opinions and comments from the professionals participating in our focus group.

In this specific chapter we are going to review in depth what spatial resolution means in order to understand the results of our fieldwork, will also be exposed and explained as mentioned before.

7.1. Characteristics and differences

As we already explained in the theoretical framework, the unit of the spatial resolution is the pixel. More resolution thus means more pixels.

The resolution of a picture is simply the total amount of pixels contained in that picture.

When talking about flat panel display devices the resolution is the total amount of pixels that the panel will use to display the contents on the screen.

Grid 6. Common resolutions in the market

Resolution names	Columns per lines	Total amount of pixels
SD	720 x 480	345.600
	720 x 576	414.720
HD Ready	1280 x 720	921.600
Full HD	1920 x 1080	2.073.600
4K	3840 x 2160	8.294.400
	4096 x 2160	8.847.360
8K	7680 x 4320	33.177.600

Source: designed by the author

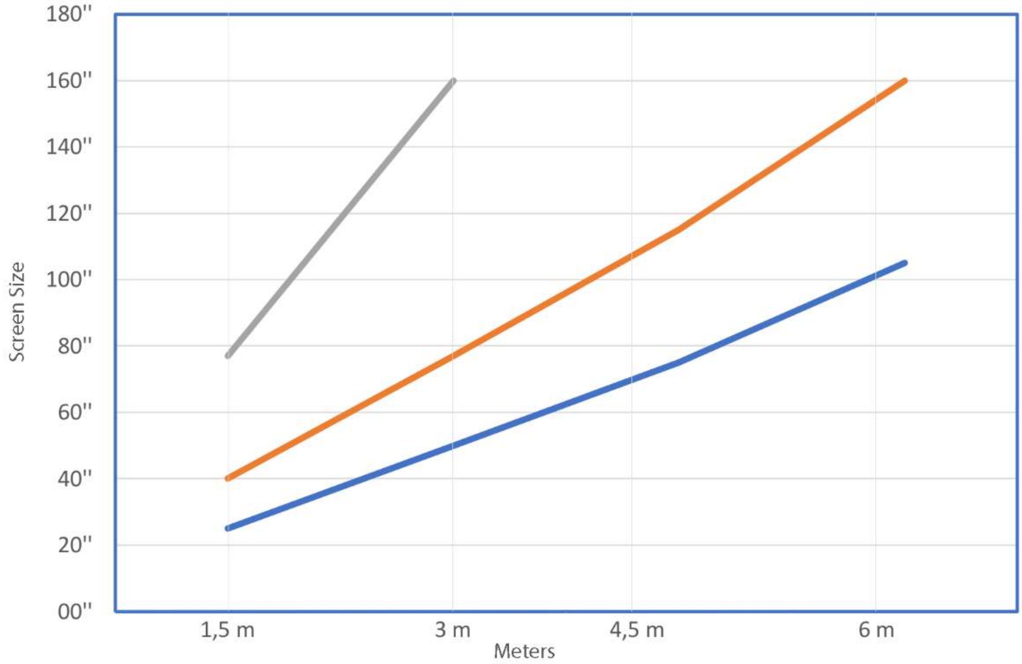
When talking about the perception of this resolution, it is important to mention the following concepts:

- Visual acuity
- Image resolution
- Screen size
- Viewing distance
- Horizontal viewing angle
- Vertical viewing angle

In order for a specific picture resolution to be perceived by the viewer, we need to take into account all these points (Le Callet and Barkowsky, 2014).

The following grid specifies how viewing distance, screen size and resolution are related in order for the viewer to perceive it properly.

Figure 17. Optimal viewing distance according to screen size and resolution.



HD Ready	25''	50''	75''	105''
Full HD	40''	77''	115''	160''
4K	77''	160''		

Source: designed by the author

This becomes a very important point since the limitations of human vision impose a very restricted resolution. Also, the limitations of human viewing angles impose a restricted panel size and so does the room size.

Is more always better? this specific point the answer is clearly no.

It is not easy to modify the factors that limit the resolving power of the eye: the diameter of the pupil and the wavelength of light.

Regardless of the detail level in the image, the human eye's ability to perceive this detail will always be restricted to its natural limitations.

An image in 4K has three times as many pixels than an image in 1080, nevertheless, if the viewing conditions are not optimal (as they are in most trade shows where this new technology is exposed to the public and media), the viewer is simply not able to notice any difference in resolution.

This situation will happen in most homes with a 4K or 8K flat panel TV display.

Most 8K opposition groups point out that there is no current 8K content to watch, but this is not really the most important argument against the technology since that situation could change very fast if this resolution proves to be a great improvement in human image quality perception.

Other opposing groups to these ultra-high resolutions (4K and 8K) highlight the fact that bandwidth limitations in current streaming technology will represent a great challenge for the industry. This is surely a more complicated problem to solve, but still not a more relevant argument than the fact that the limitations of human perception will never allow us to fully enjoy the technology in a comfortable way for home flat panel TV displays (Murnane, 2018).

7.2. Advantages and disadvantages depending on the contents: our fieldwork

After carrying out our fieldwork, we realized that the scaling process, the flat panel device applies it's a success according to the consumer panel.

The process was set as follows; we first ran the test on the QLED technology. All the members of the consumer panel watched 60 seconds of a soccer game on HD that was being scaled by the panel to its native resolution 4K. The panel size was 65". Then they answered the survey.[lxi]

After this view, they watched the same contents for the same amount of time but on 4K, matching the native resolution of the panel. Then they answered the survey.

[lxi] See annex 2.

For the second part of the resolution test, all the members of the consumer panel watched 60 seconds of the official trailer of a movie on HD that was being scaled by the panel to its native resolution 4K. After this they answered the survey.

Then they watched the same contents for the same amount of time but on 4K, matching the native resolution of the panel. Then they answered the survey.

We later repeated the same process with the panel of OLED technology (also a 65” and 4K panel), exactly with the same procedure.

The members of the consumer panel did not know at any time which display tool they were testing. They were just asked to answer which option they preferred.

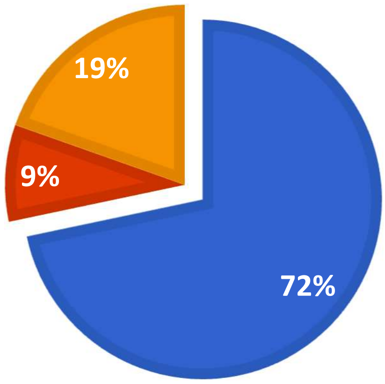
We let the members of the consumer panel choose freely between three options of viewing distance; 1,5m 2,5m and 3,5m. The most popular options were 2,5m and 3,5m and the members only chose the 1,5m option when the others were no longer available.

7.2.1. Sport contents

From the data we could collect from **QLED technology**, we saw that;

With sport contents, most viewers preferred to watch HD contents that had been scaled to UHD rather than native UHD contents on a UHD panel.

Figure 18. Graphic of viewer preferences with QLED technology and sport contents testing image resolution.



8,7%	Preferred to watch UHD contents on a native UHD panel.
19,6%	Didn't noticed any image quality difference between watching HD contents scaled to UHD on a native UHD panel and watching UHD contents on a native UHD panel.
71,7%	Preferred to watch HD content scaled to UHD on a native UHD panel.

Source: designed by the author

It is especially interesting that viewers preferred to watch scaled contents (HD contents scaled by the panel to 4K) rather than native 4K contents.

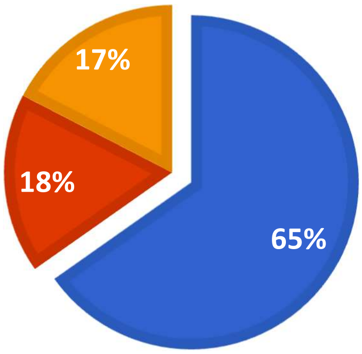
This is probably closely related with the grid of figure 17, since the viewers can't sit at the appropriate distance, they are unable to tell the difference between one resolution and the other.

This is pretty surprising because an HD resolution has a total amount of 2.073.600 pixels and a 4K has 8.294.400 pixels, which means the panel is creating by the interpolation 6.220.800 pixels that were not in the original footage of the content which is more than half the pixels of the total amount of pixels that the panel displays and more than three times the amount of pixels of the original footage of the content.

From the data we could collect from **OLED technology**, we saw the same results as with QLED;

With sport contents they preferred the scaled from HD to UHD carried out by the display rather than the native UHD contents.

Figure 19. Graphic of viewer preferences wit OLED technology and sort contents testing image resolution.



17,4%	Preferred to watch UHD contents on a native UHD panel.
17,4%	Didn't noticed any image quality difference between watching HD contents scaled to UHD on a native UHD panel and watching UHD contents on a native UHD panel.
65,2%	Preferred to watch HD content scaled to UHD on a native UHD panel.

Source: designed by the author

OLED has a little better result on viewers that preferred to watch native UHD contents but still most of them preferred the scaled version.

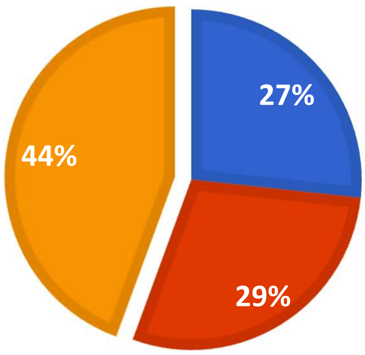
Of course, if we go back to figure 17, we realize that the optimal viewing distance for 4K resolution on a 65'' panel is not 1,5 m, 2,5 m or 3,5 m as in our sample. For a viewing distance of 1,5 m our sample should have had a 77’’ panel.

The problem is that at a shorter distance than 1,5 m the viewer cannot comfortably view the entire panel when close to a 65’’ screen; even less with a larger size.

7.2.2. Cinematographic contents

As for cinematographic contents on **QLED technology**, almost half of the sample didn’t notice the difference between the scaled content from HD to UHD and the native UHD content.

Figure 20. Graphic on viewer preferences with QLED technology and cinematographic contents testing image resolution.



28,9%	Preferred to watch UHD contents on a native UHD panel.
44,4%	Didn’t notice any image quality difference between watching HD contents scaled to UHD on a native UHD panel and watching UHD contents on a native UHD panel.
26,7%	Preferred to watch HD content scaled to UHD on a native UHD panel.

Source: designed by the author

This data is very meaningful since it indicates that there is no need at all for an increase of the resolution in the industry.

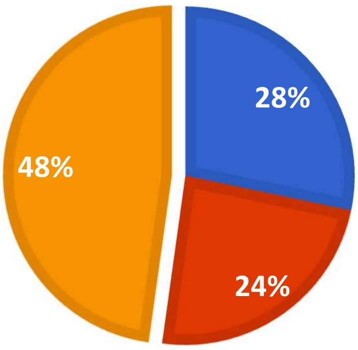
Viewers on our consumer panel were sitting at the following distances from the 65” 4k panel: 1,5 m, 2,5 m and 3,5 m. When choosing the distance freely they all preferred 2,5 and 3,5m over 1,5m. This means that, for the aforementioned viewing distances, -the most common ones on a living room- the viewers can't really tell the difference between one resolution and the other.

For them to be able to notice any difference at 1,5 m distance, the panel size would need to be 77" and would thus be very uncomfortable to look at.

From the data we could collect from **OLED technology**, we saw the same results as with QLED;

For the cinematographic contents, almost half of the sample did not notice the difference between the scaled content from HD to UHD and the native UHD content.

Figure 21. Graphic on viewer preferences with OLED technology and cinematographic contents testing image resolution.



23,9%	Preferred to watch UHD contents on a native UHD panel.
47,8%	Didn't notice any image quality difference between watching HD contents scaled to UHD on a native UHD panel and watching UHD contents on a native UHD panel.
28,3%	Preferred to watch HD content scaled to UHD on a native UHD panel.

Source: designed by the author

On this point there were no significant differences between OLED and QLED technologies, it becomes clear that an increase of image resolution is not needed since it will not be noticed.

7.2.3. Our experts said

When consulting our experts in the focus group the same result occured, most of them couldn't tell the difference between the native resolution and the scaled one for OLED and preferred the scaled version for QLED. It started to become very obvious that; viewing distance and panel size are crucial to appreciate resolution.

If not even an expert eye can tell the difference it seems very clear that human visual acuity's limitations affect image resolution on the aforementioned terms.

7.2.4. Results

It is important though to underline the fact that viewers preferred the scaled version rather than the one using its original resolution for sport contents.

The sport contents don't have special lighting with dramatic intention; the elements in these contents move very fast all over the screen constantly and are generally recorded at very high shutter speeds.

Even though we know that the best resolution happens when the contents and display device's resolutions match, in this case viewers don't give more importance to image quality.

For this kind of contents, viewers give more importance to other elements like seeing the big picture or having smoother images.

Image 1. Freeze frame from the contents displayed during the consumer panel.

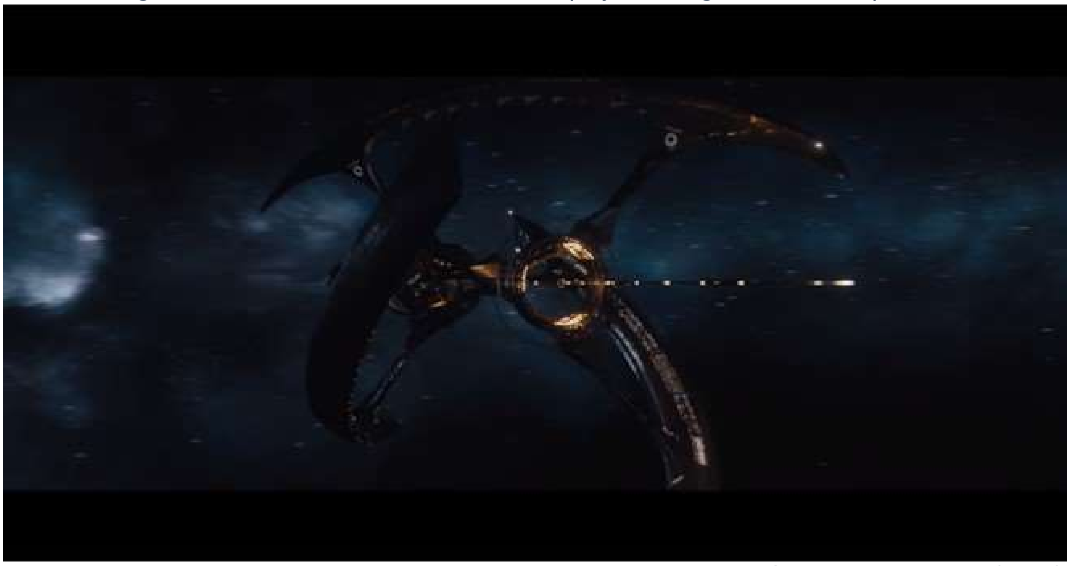
Source: Match of the day

As for the cinematographic contents, we get back to the grid. Our viewers were seated at 1,5 m, 2,5 m and 3,5 m distance from a 65’’ screen and could thus not be able to notice any resolution difference.

As the grid explains, in order to notice any resolution difference for 4k at 1,5 m distance the perfect panel size would have been 77’’.

The problem is that the viewers could never have seen the whole screen in a comfortable way if it had been that big and that close.

Image 2. Freeze frame from the contents displayed during the consumer panel.



Source: Passengers (2016)

Cinematographic contents do have special lighting with a dramatic intention; The reason why the scaling system is a success is that it doesn’t alter the lighting much and therefore does not drastically affect the aesthetic purpose of the content.

Of course, as mentioned in chapter 6, the scaling system draws new pixels and the resulting content is consequently different from the original content, but the other option would be to leave part of the panel without signal.

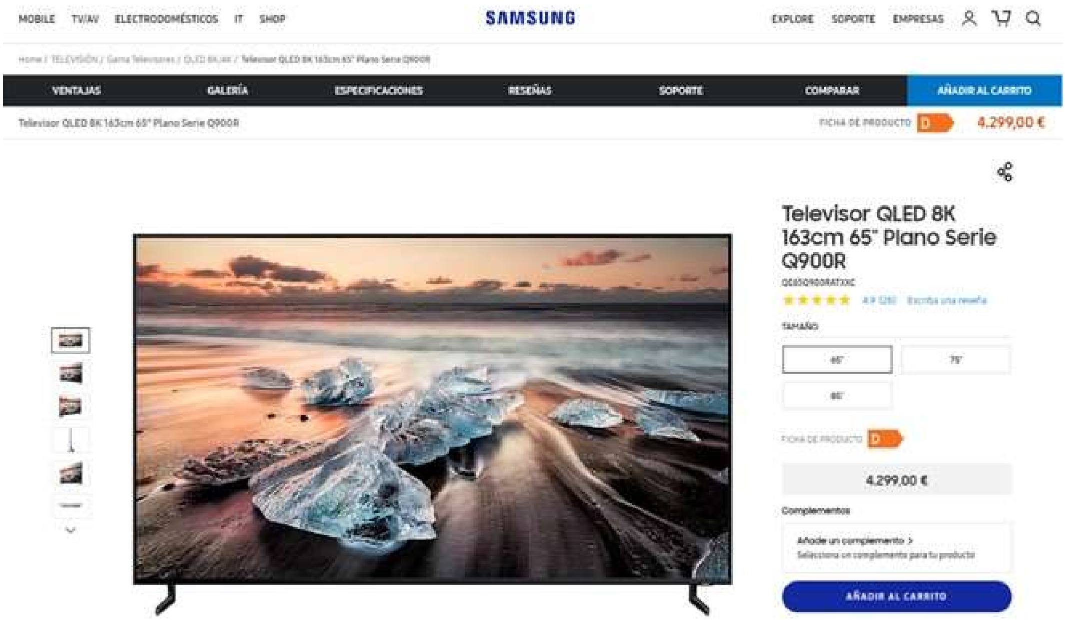
The weak point in this case is the resolution of the panel. It shows that a 4K panel cannot be purely enjoyed by the viewers in comfortable conditions since the optimal viewing distance cannot be respected and thus the audience is unable to appreciate the difference in resolution.

After consulting our experts in the field during our focus group, most of them were unable to notice any resolution (between native and scaled) difference even with an expert’s eye when sitting at 2,5 m distance from the panel (they were also free to choose their viewing distance).

If the experts themselves were not able to notice a difference, this leads us to conclude that it is a matter of human visual acuity as explained in Figure 17.

This is leads us to a deep reflection on the advantages of increased panel resolution with Samsung now launching its new product QLED with an 8K resolution on panels of 65’’ size. Since nobody can sit that close to the panel and see it all, no viewer would be able to fully enjoy this increase of image resolution.

Image 3. Samsung QLED 8K 65’’



Source: Samsung (2019)

8. Temporal Resolution

8. Temporal Resolution

In this chapter we will review the temporal resolution concept to be able to understand how it affects human perception in order to understand the results of our fieldwork that will also be exposed and explained.

8.1. Characteristics and differences

As we already mentioned in the theoretical framework, temporal resolution is formed by two different concepts: frame rate and refresh rate.

The frame rate is the amount of frames per second the contents are recorded with. The refresh rate is the amount of times per second the panel displays one frame.

All flat panel TV displays suffer from “motion blur”. This effect is actually created by our brain and retina since our eyes are constantly moving when reading the information displayed on the screen. When this information is moving, like a moving subject or a camera motion, our eyes are already looking for the following position of the subject on the screen or the next action which creates this blur effect across our retinas.

This is why many manufacturers assume that a higher refresh rate yields a smoother motion that will look more natural (Morrison, 2015b)(Rejhon, 2018).

If a flat panel TV display has a refresh rate of 120Hz and the incoming signal is at 24 fps, there would be 94 new frames created by the display; This means that each different picture is repeated 5 times every 24th of a second. To do so, the panel can display 5 times the same frame or it can create new frames between the original ones.

If a panel has a refresh rate of 120Hz and the film runs at 24 frames per second, this means that the panel needs to create 3 new frames between original ones.

If the panel has a refresh rate of 240Hz then the amount of new frames can be between 2 and 8.

This last option is what we call **motion interpolation**. This process of creating new frames is done through a digital analysis of surrounding frames. Once done, this data is used to create the new intermediary frames. This system's goal is to create a more natural looking picture, but at the same time it creates another side effect known as the "**soap opera effect**".

This effect results from motion interpolation and it consists of contents with a specific aesthetic purpose (like films or advertisements) losing its cinematographic look. Thus, those contents will no longer have their specific aesthetic purpose since motion interpolation will make them look absolutely different in terms of looks (Rouse, 2010).

As a conclusion, if we are watching contents at 240Hz of refresh rate, with the motion interpolation tool on, for a frame rate of 24, we are watching 24 original frames and 216 interpolated frames that were not in the original footage.

If we are watching contents at 120Hz of refresh rate, with the motion interpolation tool on, for a frame rate of 24, we are watching 24 original frames and 96 interpolated frames that were not in the original footage. In both scenarios, we would be watching more interpolated frames than original ones.

8.2. Advantages and disadvantages depending on the contents: Our fieldwork

After carrying out our fieldwork, we realized that the motion interpolation tool the flat panel device applies is a failure according to the consumer panel.

The process was set as follows; we first ran the test on the QLED technology. All the members of the consumer panel watched 60 seconds of a tennis game with the motion interpolation tool on. Then they answered the survey.[lxii]

After this viewing, they watched the same contents for the same amount of time but with the motion interpolation tool off. Then they answered the survey.

For the second part of the temporal resolution test, all the members of the consumer panel watched 60 seconds of the official trailer of a series with the motion interpolation tool off. After this they answered the survey.

Then they watched the same contents for the same amount of time but with the motion interpolation tool on. Then they answered the survey.

We later repeated the same process with the panel of OLED technology, using exactly the same procedure.

The members of the consumer panel did not know at any time which display tool they were testing. They were just asked to answer which option they preferred.

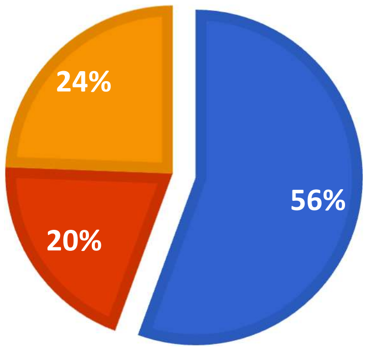
[lxii] See annex 2.

8.2.1. Sport contents

From the data we could were able to collect from **QLED technology**, we saw that;

With sport contents, the tool did not work at all; Most of the viewers preferred it off.

Figure 22. Graphic on viewer preferences with QLED technology and sport contents testing motion interpolation tool.



20%	Preferred to watch the contents with the motion interpolation tool on.
24,4%	Did not notice any image quality difference between watching the contents with the motion interpolation tool on and off.
55,6%	Preferred to watch the contents with the motion interpolation tool off.

Source: designed by the author

This means a big failure of the tool since it was specifically designed for sport contents.

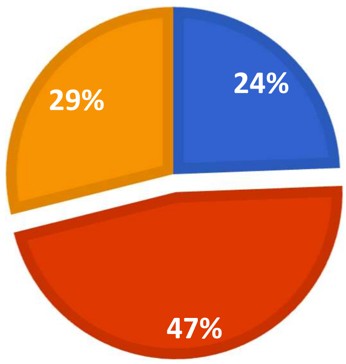
The purpose of motion interpolation was to make motion more fluid and reduce motion blur; Sport contents have a lot of motion and very small elements moving at high speed across the panel (like the ball) and this tool was designed to eliminate the blurring of elements across the panel.

When consulting our experts in the focus group the same result occured, they noticed image freezing across the panel when the tool was on.

From the data we could collect from **OLED technology**, we also see negative results for the motion interpolation tool since most viewers preferred it off or do not notice any difference with sport contents.

There is however, a significant increase in the number of viewers that prefer it on with OLED technology than with QLED. On this point there is clearly a preference from the viewers towards the OLED interpolator.

Figure 23. Graphic on viewer preferences with OLED technology and sport contents testing motion interpolation tool.



46,7%	Preferred to watch the contents with the motion interpolation tool on.
28,9%	Did not notice any image quality difference between watching the contents with the motion interpolation tool on and off.
24,4%	Preferred to watch the contents with the motion interpolation tool off.

Source: designed by the author

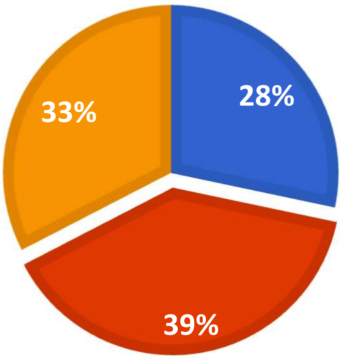
Since this tool was specifically designed to improve the viewer's experience with sport contents the fact that a significant part of the sample (28,9%) didn't notice any difference also means a big failure.

The data that however stands out is the 47% of the sample that preferred to watch the sport contents with the motion interpolation tool on since only 20% preferred it on for the same contents with QLED technology.

8.2.2. Cinematographic contents

As for cinematographic contents the motion interpolation tool fails too. With **QLED technology** more than half the sample preferred it off or didn't notice the difference (in this case, not noticing the difference means a failure since it's a tool that is supposed to improve the viewer's experience).

Figure 24. Graphic on viewer preferences with QLED technology and cinematographic contents testing motion interpolation tool.



39,1%	Preferred to watch the contents with the motion interpolation tool on.
32,6%	Did not notice any image quality difference between watching the contents with the motion interpolation tool on and off.
28,3%	Preferred to watch the contents with the motion interpolation tool off.

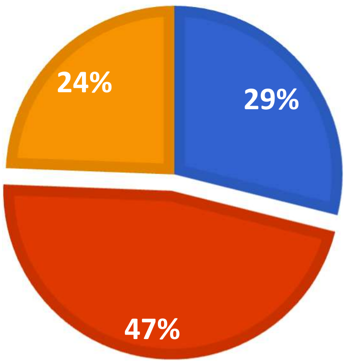
Source: designed by the author

Since this tool is supposed to create a more natural looking picture it is relevant that a 32% of the sample didn't even notice the difference.

But the most shocking data is that almost double the amount of viewers preferred the tool on with cinematographic contents rather than with sport contents using the same technology since, as mentioned before, it is a tool that was specifically designed for sport contents and its main objective was to solve motion blur problems for very high speeds -subjects inside the frame moving at high speeds-

From the data we were able to collect from **OLED technology**, this was also unsuccessful, with cinematographic contents: more than half the sample didn't notice any difference or preferred the motion interpolation tool off.

Figure 25. Graphic on viewer preferences with OLED technology and cinematographic contents testing motion interpolation tool.



46,7%	Preferred to watch the contents with the motion interpolation tool on.
24,4%	Did not notice any image quality difference between watching the contents with the motion interpolation tool on and off.
28,9%	Preferred to watch the contents with the motion interpolation tool off.

Source: designed by the author

In OLED technology the results don't vary much according to the nature of the contents, only a slight increase in the amount of viewers that preferred it off rather than not noticing any difference, probably due to the aesthetic purpose of the contents.

This result was more predictable since the motion interpolation tool modifies the aesthetics of the contents and cinematographic contents have a very specific aesthetic purpose.

But again, we see that the tool is more accepted on OLED technology than on QLED.

8.2.3. Our experts said

When discussing these results with the experts at our focus group the dynamic range automatically came out, with OLED technology being able to create more pure blacks (Figure 12, chapter 5) for being an emissive panel (Figure 8, chapter 5); The tool is more accepted with this technology.

But the most surprising result is the fact that viewers preferred the tool with cinematographic content over the tool with sport contents.

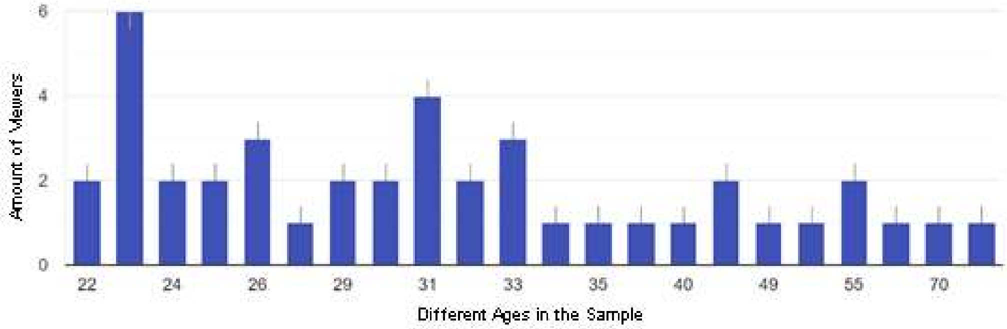
47% of the sample preferred to watch cinematographic contents with the motion interpolation tool on with OLED technology and 39% of the sample preferred to watch cinematographic contents with the motion interpolation tool on using QLED technology.

These results were unexpected since, as mentioned before, the motion interpolation tool does modify the aesthetics of the contents which are very specific on cinematographic content.

This supposedly more natural-looking image happens to modify the aesthetic purpose of the cinematographic content, but some viewers didn’t dislike it.

The conclusions, after discussing the results with the experts of our focus group pointed all in the same direction: the average age of the sample.

Figure 26. Average age of sample.



Source: designed by the author

As we can observe on Figure 26, the majority of the sample is around 23 years old. This range of the audience is very used to videogames and the aesthetics of video games are very particular, having a very high amount of image detail and high brightness; two characteristics conflicting with traditional cinema.

Thus, this change in the aesthetics of the contents, though perceived as very negative by all the experts from our focus group, was perceived as something positive by the younger viewers.

Due to this change of aesthetics, younger viewers are more likely to perceive this tool as something positive. The experts; on the contrary, claimed that the tool is completely ruining the hard work of the cinematographer. They all agreed that this tool should be deactivated by default and that it should only work with sport contents.

Image 4. Freeze frame from counter strike video game online.

Source: Gamezone.com

As the industry of videogames has been growing incessantly, so has its level of image detail; Thus our experts concluded that this new aesthetic, imposed through videogames, is increasingly more accepted by the audience rather than the old cinematic style.

Image 5. The last emperor, 1987. Direction: Bernardo Bertolucci, DoP: Vittorio Storaro.

Source: The last emperor (1987)

8.2.4. Results

These results are very surprising and interesting. We did expect the viewers to dislike the tool for cinematographic contents since it changes the looks and cinematographic contents have a very specific aesthetic purpose.

We didn't expect the tool to fail as well with the contents for which it was specifically designed.

Image 6. Freeze frame from the contents displayed during the consumer panel.

Source: Diario as

When it comes to sport contents, the results lead us to conclude that the resulting image is far more unnatural than the one affected by the motion blur effect that it was supposed to correct.

Nevertheless, it is necessary to point out that the tool is broadly more accepted by the viewers with sport contents on OLED technology (47%) than on QLED (20%).

These results clearly expose the quality of the QLED interpolator, since it is broadly rejected by the viewers.

Image 7. Freeze frame from the contents displayed during the consumer panel.

Source: Stranger Things (2017)

When it comes to cinematographic contents the results were similar.

Most of the samples in both technologies preferred it either off or didn't notice any difference with OLED 53% (24% didn't notice any difference and 29% preferred it off) and QLED 61% (33% didn't notice any difference and 28% preferred it off).

Still, as with the sport contents, the tool is more accepted for cinematographic contents with OLED (47%) than with QLED (39%).

9. Bit Depth and Color Space

9. Bit Depth and Color Space

As mentioned in the theoretical framework, the bit depth indicates the number of bits used for each color component of a single pixel (RGB): the more bits used to indicate the color, the more shades of grey are shown, but that color will always be limited to a specific color gamut in a specific color space.

A color space[lxiii] is a specific organization of colors that relates colors to numbers in a three-dimensional form (X, Y and Z) that can create all possible color combinations within the gamut.

Going back to bit depth (also known as color depth since it specifies the amount of shades of grey), some amounts have become standards after the years.

The aforementioned 709 (*itu.int*, 1990), defined an 8 bit or 10 bit for high resolution television.

Grid 7. Bit depth values

Bits per Color component	Shades Per color component	Total amount of bits	Possible color combinations
1	2	3	8
2	4	6	64
4	16	12	4096
8	256	24	16.777.216
10	1024	30	1.073.741.824
12	4096	36	68.719.476.736

Source: designed by the author

[lxiii] See Theoretical Framework

As we can see on grid 7, the more bits sent, the more possible color combinations. And as we have seen in figure 7[lxiv], the wider the palette, the more color options to choose amongst.

But these two features are going to be affected by a tool from the flat panel TV display device: the image modes.

Image modes can come with different names depending on the brand "vivid", "dynamic", "sports", "cinema", "natural" but they are present in the great majority of flat panel TV display devices.

When the tool first appeared, all panels were coming out of the box with the "dynamic or vivid" mode on by default as explain the state of the art.

Nowadays this has changed and once the flat panel TV display has been tuned for the first time, the menu will ask you to choose an option for most of the panels, and sometimes this can even lead to a very dull image that help manufacturers reach low energy consumption levels. But that does not mean that the panel is not applying an image mode. (Willcox, 2019)

[lxiv] See Theoretical Framework

9.1. Advantages and disadvantages depending on the contents: our fieldwork

After carrying out our fieldwork, we realized that the image modes offered by the flat panel device are a failure according to the consumer panel.

The process was set up as follows; we first ran the test on the 10 bit panel QLED technology. All the members of the consumer panel watched 60 seconds of a formula 1 race with the sport mode on. Then they answered the survey.[lxv]

After this view, they watched the same contents for the same amount of time but with the sport mode off. Then they answered the survey.

For the second part of the image mode test, all the members of the consumer panel watched 60 seconds of the official trailer of a movie with the cinema mode off. After this they answered the survey.

Then they watched the same contents for the same amount of time but with the cinema mode on. Then they answered the survey.

We later repeated the same process with the 10 bit panel of OLED technology, exactly with the same procedure.

The members of the consumer panel did not know at any time which display tool they were testing. They were just asked to answer which option they preferred.

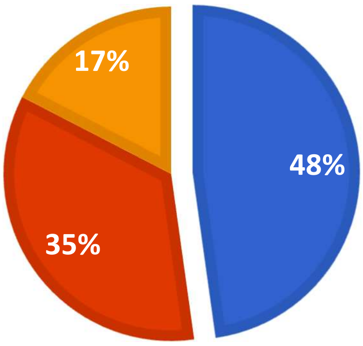
[lxv] See annex 2.

9.1.1. Sport contents

From the data we could collect from **QLED technology**, we saw that:

With sport contents, most viewers prefer to watch the contents with the sport image mode off or do not even notice the difference.

Figure 27. Graphic of viewer preferences with QLED technology and sport contents testing image modes.



34,8%	Preferred to watch the contents with the sports mode on.
17,4%	Did not notice any image quality difference between watching the contents with the sports mode on and off.
47,8%	Preferred to watch the contents with the sports mode off.

Source: designed by the author

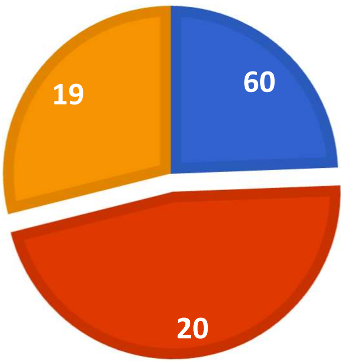
It is very remarkable that 48% of the sample preferred to watch the sport contents with the sport image mode off. 70% of the sample preferred it off or didn't notice any image quality difference. This means a big failure for this tool on this technology.

Even if sports do not generally have a specific aesthetic purpose, this test made clear that the tool turned out to be neither natural nor agreeable to the great majority.

From the data we were able to collect from **OLED technology**, we saw similar results as with QLED;

With sport contents more than half of the sample prefer to watch the contents with the sport image mode off.

Figure 28. Graphic on viewers preferences with OLED technology and sport contents testing image modes.



19,6%	Preferred to watch the contents with the sports mode on.
19,6%	Did not notice any image quality difference between watching the contents with the sports mode on and off.
60,9%	Preferred to watch the contents with the sports mode off.

Source: designed by the author

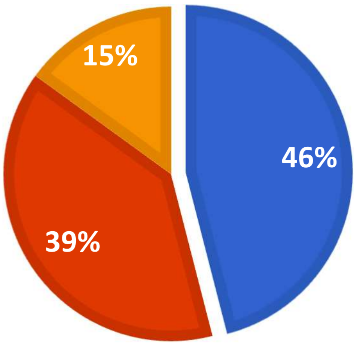
There is however, an important difference to outline, only 19,6% of the sample preferred to watch the sport contents with the sport image mode on with OLED when 35% with QLED technology. This reperesents an increase of 15% from one technology to the other.

80,6% of the sample preferred it off or did not notice any image quality difference, which means a failure of the tool regarding this technology.

9.1.2. Cinematographic contents

As for the cinematographic contents of **QLED technology**, more than half of the sample did not notice the difference or preferred to watch the contents with the cinema image mode off.

Figure 29. Graphic of viewer preferences with QLED technology and cinematographic contents testing image modes.



39,1%	Preferred to watch the contents with the cinema mode on.
15,2%	Did not notice any image quality difference between watching the contents with the cinema mode on and off.
45,7%	Preferred to watch the contents with the cinema mode off.

Source: designed by the author

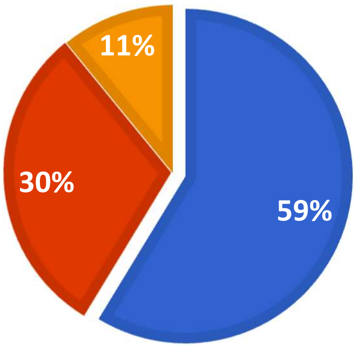
Again, very negative results for QLED on the image mode test with 46% of the sample preferring to watch the cinematographic contents with the cinema image mode off. And 61% of the sample preferred it off or did not notice any image quality difference.

However, 39% preferred to watch the contents with the cinema mode on with QLED when only 30% preferred it on with OLED, this means a victory the QLED technology over OLED for this specific tool with both contents: cinematographic and sports.

From the data we were able to collect form **OLED technology**, we saw similar results as with sport contents;

For the cinematographic contents from the data we were able to collect from OLED technology, more than half of the sample does not notice the difference between watching the contents with the cinema image mode on or off or preferred to watch the contents with the cinema image mode off.

Figure 30. Graphic on viewers preferences with OLED technology and cinematographic contents testing image modes.



30,4%	Preferred to watch the contents with the cinema mode on.
10,9%	Did not notice any image quality difference between watching the contents with the cinema mode on and off.
58,7%	Preferred to watch the contents with the cinema mode off.

Source: designed by the author

59% of the sample preferred to watch the cinematographic contents with the cinema mode off. This is a very negative result for this tool concerning this technology.

Another victory from QLED technology's tools over OLED's, 8% more preferred to watch it on with QLED.

70% of the sample preferred it off or did not notice any image quality difference. Another failure for the technology's tool since with sport contents, 80% preferred it off or did not notice the difference.

9.1.3. Our experts said

All of our experts rejected the image mode tool. Since it drastically changes de aesthetic purpose of the content, they considered that the tool should be off by default or not present at all in the panel.

Nevertheless, they add that it was more difficult for them to detect whether it was on or off since it modifies all the aesthetics from beginning to end and thus, unless watching a content that is familiar to you, it is more complicated to spot it than other tools from the panel such as the motion interpolation tool or the HDR effect.

It was very interesting though that more than half of the sample (70% -QLED- and 80% -OLED-) preferred it off or did not notice any difference with sport contents and similarly (60% -QLED- and 70% -OLED) with cinematographic contents even when they could not possibly be familiar with the aesthetic purpose of the displayed contents since it was a formula 1 race (with no specific aesthetic purpose) and the trailer from a non-released movie.

After all, an image mode is nothing but a kind of LUT (lookup table), a color preset that does film emulation, cinema styling or other desired styles (Yeager, 2016).

An image mode adjusts several parameters for this purpose such as contrast, brightness, color, tint, sharpness and color temperature.

A cinematographic image mode will get darker blacks and brighter whites, a warmer color temperature with a red or yellow tint.

A sports image mode will make primary colors look brighter (e.g. greens and blues for football) and gives a cooler color temperature.

For sports, since there is no specific aesthetic purpose, this might not be a problem and yet it was rejected with worst data than cinematographic contents on both technologies. Cinema, however, since having a very specific aesthetic purpose, it drastically modifies the intention of the cinematographer even when trying to get a more “cinema like” look.

Image 8. Freeze frame from the contents displayed during the consumer panel.

Source: Beauty and Beast (2017)

As for the case of the image modes, it clearly shows that, even though viewers could accept that the aesthetics of the film could be the ones applied by the LUT of the cinema image mode, these are mainly rejected.

Since we tested the tool with the trailer of a film that was not yet released and with a formula 1 race, viewers had no prior clear idea of what the aesthetics of the contents were.

If we had tested the tool with a famous series or advertisement, viewers would have rejected it massively since it modifies the aesthetics they are expecting.

Image 9. Freeze frame from the movie Captain Marvel with Dynamic image mode on.

Source: designed by the author

Image 10. Freeze frame from the movie Captain Marvel with standard image mode on.

Source: designed by the author

Image 11. Freeze frame from the movie Captain Marvel with cinema image mode on.

Source: designed by the author

Image 12. Freeze frame from the movie Captain Marvel with Natural image mode on.

Source: designed by the author

As we can appreciate in these examples, all image modes drastically modify the aesthetic purpose of the contents. This fact affects more the contents with a specific aesthetic purpose like films, advertisings, etc.

As we can see in image 9, the dynamic image mode applies a filter that enhances brightness, all colors seem more vivid, more saturated and the image is highly sharpened.

In image 10, we see that the standard (no filter applied) is duller, nothing stands out from the picture.

In image 11, the natural image mode makes a more balanced image in terms of colors, it highlights skin tones and blues.

In image 12, the cinema image mode applies a sepia filter to the footage.

Watching the film with one image mode or another implies watching a completely different film in terms of cinematography.

This reinforces the proof that image modes modify the aesthetic purpose of the contents, yet some viewers don't seem to dislike it (39% -QLED- and 30% OLED) since, for cinema mode, the tool uses a filter based on a film aesthetic that has been in the industry for decades and thus, viewers accept or believe, that the film was shot that way.

Anyone could criticize the aesthetics of the film without knowing that it is actually the tool applied by the panel which designates the aesthetics.

It also brings us back to bit depth and color space. It has always been accepted by the industry that the wider and deeper the color space and bit depth, the better. Basically because, it implies more shades of grey and more options in the palette. But this tool applies the same filter to every film, the same to every sports event, which means that all cinematographic contents will have the same aesthetics despite the intention of the filmmaker and likewise for sports.

If this tool had succeeded it could have meant that all films would have had the same aesthetics, suggesting the demise of cinematographers as professionals.

During the focus group discussions, some pointed out that these options should not be available on the panel, not even available to expert user only.

Obviously, if this tool had succeeded it could have meant that bit depth and color space were not important anymore since all contents were to be displayed with the exact same colors and shades of grey after applying the same filters to all of them.

9.1.4. Results

Image 13. Freeze frame from the contents displayed during the consumer panel.

Source: F1 Australia (2012)

However, we must mention that the tool had better acceptance in this case for QLED than for OLED with both contents: 15% more acceptance for sport contents and 9% for cinematographic contents. Which does not mean that QLED is not modifying the aesthetic purpose, just that it seems more natural or realistic for viewers that the contents were shot that way (specially for sport contents), thus, we can conclude that the tool was better designed regarding that technology.

10. Dynamic range: SDR and HDR

10. Dynamic range: SDR and HDR

As mentioned in the theoretical framework, the dynamic range is the difference between the darkest black and the lightest white of an image, the larger the dynamic range, the greater the image's difference in brightness values.

We can measure the dynamic range in f-stops on a camera (the larger the amount of f-stops, the greater the camera's dynamic range and vice versa) or in contrast ratio such as 100:1 (100 being the white and 1 the black) on a panel or projector.

An SDR image (Standard dynamic range) has around 6 f-stops while an HDR image (High dynamic range) has around 15 f-stops.

Due to this enormous difference in brightness performance, an HDR image shows a lot more information in highlights and shadows than an SDR.

This is perceived by the viewer as a wider range of color (though it is actually more shades of grey), and more overall detail.

Until the year 2017, there were two formats for HDR:

Dolby Vision, that requires a panel with a Dolby vision hardware chip, and HDR10, a more easily adoptable standard used by manufacturers.

In 2017 HDR 10 + was launched. In 2018 the BT.2100 specified two standards for HDR: HLG and PQ (the basis of Dolby Vision and HDR 10) and in 2020 a new HDR format was announced: the Dolby Vision IQ.

That meant one HDR format released per year though the standard coming from the ITU talks about two different formats. Having so many HDR formats makes it difficult for the technology to find stability.

It is no longer difficult to find HDR content since platforms such as Netflix (on Windows 10) and Amazon Prime are already offering it.

Image 15. SDR image where we lose information in dark areas (underexposed).

Source: Creative Rebellion

Image 14. SDR image where we lose information in white areas (overexposed).

Source: Creative Rebellion

Image 16. HDR image where we have information in both dark and white areas.

Source: Creative Rebellion

As we can see on image 14, when a camera has low dynamic range (around 9, 10, 11 f-stops) we need to choose which part of the images is going to have detail. In this case, all the information is in the highlights, we can see the clouds, sun rays and the edges of the clouds lit by the sunrays. We even see the defined silhouette of buildings on the horizon.

However, there is no information at all in the dark area, we only perceive the silhouette of what looks like a couple, but we don't know their exact position, what they are wearing or even immediately in front of them since it all appears as a black stain.

If we have a look at image 15, we find the opposite result to image 14. Another low dynamic range camera is used (9, 10 or 11 f-stops). Here all the information is in the darkest area of the image. We see a couple in the foreground, we can perceive every detail there, what they are wearing, their skin tones, their position, we also see the midground, what looks like a hill with trees and houses.

In this case, the background is absolutely overexposed. The latitude of the camera (its dynamic range) was not wide enough to capture both areas so the sky is totally burned. We cannot see any cloud, or sun or rays, we can only perceive some vague silhouettes of buildings but without detail or texture.

Finally, in image 16 we have the same scene but with a high dynamic range camera (14, 15, 16 f-stops). In this image, there is information on every area, regardless of its lighting conditions. We can see the foreground, the couple, their position, tones and texture, we see the middle ground, the hill with its trees and houses, and there is also information on the background: we see the clouds, light rays and the silhouette of buildings.

When comparing the texture and detail of the dark area of images 15 and 16 we obviously see a brightness difference. The same thing happens when comparing the highlighted areas of images 14 and 16; the sharpness is not the same, but there is an overall improvement in the amount of image information when comparing SDR images 14 and 15 with HDR in image 16.

This new technology claims to be the beginning of a revolution in the film and television industry.

The reason for HDR being of such importance for the TV industry is due to the fact that our eyes can perceive brighter whites and darker blacks than the ones displayed with SDR technology (Roberts, 2019).

Human vision has around 20 f-stops or 1.048.576:1 contrast ratio of dynamic range.

With SDR technology, only 6 f-stops or 64:1 contrast ratio of dynamic range.

With HDR technology, 15 f-stops or 32.768:1 contrast ratio of dynamic range (Sudhakaran, 2012).

This great improvement in dynamic range is especially important in image perception since, even if it is extending the greyscale, humans perceive different shades of grey as different nuances in color hues, thus resulting in a richer image in terms of color perception and grey scale.

In this context, color accuracy refers to how colors on the screen are similar to colors in real life (Kanchwala, 2019).

10.1. Advantages and disadvantages depending on the content: our fieldwork

After carrying out our fieldwork, we realized that the HDR effect the flat panel device has is a failure according to the consumer panel.

The process was set up as follows:

We first ran the test on the QLED technology. All the members of the consumer panel watched 60 seconds of a TV night show (SDR content) with the HDR effect tool off. Then they answered the survey.[lxvi]

After this view, they watched the same contents for the same amount of time but with the HDR effect tool on. Then they answered the survey.

For the second part of the HDR effect tool test, all the members of the consumer panel watched 60 seconds of the official trailer of a science fiction movie (SDR content) with the HDR effect tool on. After this they answered the survey.

Then they watched the same contents for the same amount of time but with the HDR effect tool off. Then they answered the survey.

We later repeated the same process with the panel of OLED technology, with exactly the same procedure.

The members of the consumer panel did not know at any time which display tool they were testing. They were just asked to answer which option they preferred.

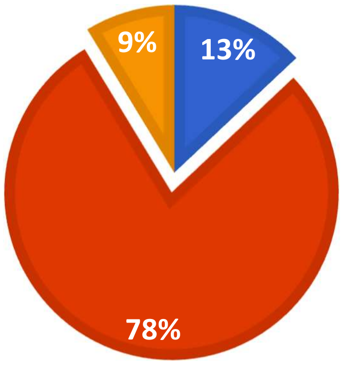
[lxvi] See annex 2.

10.1.1. Television contents

From the data we were able to collect from **QLED technology**, we saw that;

With television contents, most viewers prefer to watch the contents with the HDR effect off.

Figure 31. Graphic on viewers preferences with QLED technology and television content testing HDR effect.



78,3%	Preferred to watch SDR contents with the HDR tool off.
8,7%	Did not notice any image quality difference between watching SDR contents with the HDR tool on and off.
13%	Preferred to watch SDR contents with the HDR tool on.

Source: designed by the author

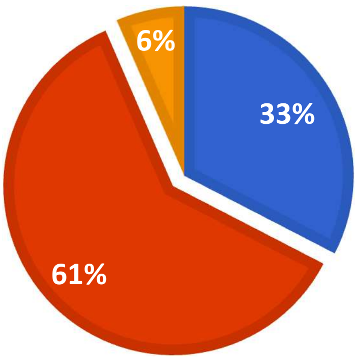
The HDR effect has been greatly rejected by the viewers in all tests, but the most dramatic results, with 78% of the sample preferring to watch the contents with the effect off, is for QLED technology with television contents.

The part of the sample where the viewers perceived no difference, added to those that preferred it off, represented 87% of the sample. This is the biggest failure of purpose of a technological tool in all the different tests we ran.

From the data we were able to collect from **OLED technology**, we saw similar results as with QLED;

With television contents more than half of the sample preferred to watch the contents with the HDR effect off.

Figure 32. Graphic on viewers preferences with OLED technology and television contents testing HDR effect.



60,9%	Preferred to watch SDR contents with the HDR tool off.
6,5%	Did not notice any image quality difference between watching SDR contents with the HDR tool on and off.
32,6%	Preferred to watch SDR contents with the HDR tool on.

Source: designed by the author

These results are largely better with OLED technology with a 17% of improvement over QLED technology, but still an enormous failure of the tool with very bad results for OLED with 61% of the sample preferring the tool off.

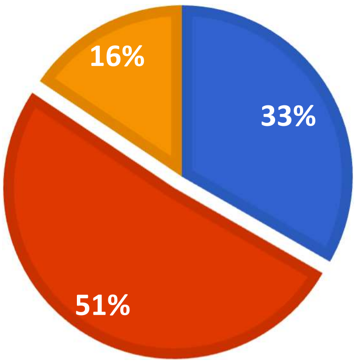
67% of the sample did not notice any difference or preferred it off.

Those are the worst results for both technologies, when testing the HDR effect on television contents.

10.1.2. Cinematographic contents

As for cinematographic contents using **QLED technology**, more than half of the sample preferred to watch the contents with the HDR effect off.

Figure 33. Graphic on viewers preferences with QLED technology and cinematographic contents testing HDR effect.



51,1%	Preferred to watch SDR contents with the HDR tool off.
15,6%	Did not notice any image quality difference between watching SDR contents with the HDR tool on and off.
33,3%	Preferred to watch SDR contents with the HDR tool on.

Source: designed by the author

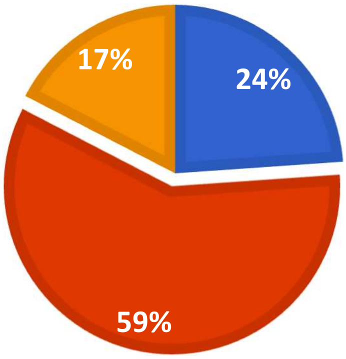
In this test QLED technology leads OLED on viewers preferences (only 7%) but still the results are not positive at all with 51% of the sample preferring to turn the effect off.

67% of the sample did not notice any difference or preferred it off.

From the data we were able to collect form **OLED technology**, we saw similar results as with television contents;

For the cinematographic contents from the data we collected from OLED technology more than half of the sample prefer to watch the contents with the HDR effect off.

Figure 34. Graphic on viewers preferences with OLED technology and cinematographic contents testing HDR effect.



58%	Preferred to watch SDR contents with the HDR tool off.
17,4%	Did not notice any image quality difference between watching SDR contents with the HDR tool on and off.
23,9%	Preferred to watch SDR contents with the HDR tool on.

Source: designed by the author

And again, a big failure with 59% of the sample preferring to turn the HDR effect off. 76% of the sample did not notice any difference or preferred it off.

In this test the OLED tool is worst rated than QLED's.

10.1.3. Our experts said

When discussing with the experts at our focus group they claimed that it modifies the chroma to a point that it turns out to be disagreeable.

The fact is that HDR was designed to go together with other parameters such as 10 bit of bit depth and a BT.2020 color space and this is not the case of those panels yet.

Another fact the experts pointed out at our focus group was that it doesn't seem like the tool is adapting to the nature of each shot (some shots can be very dark, others very bright, others can be both, etc) but instaead applies a kind of filter to the entire footage without taking into account the nature of the shots.

This consequently drastically changes the aesthetic purpose of the contents, which is why, for this test, we used a television program and a film.

As mentioned in Chapter 2, the new BT.2100 specified the format for broadcasting HDR and it included the same color space as BT.2020 (that covers 75,8% of the spectrum) and 10 or 12 bits of bit depth.

This drastic rejection by the viewers of the HDR effect leads us to think that HDR needs to be original from its content for it to properly adapt to the nature of each shot. It does not seem legitimate to call the tool “HDR effect” when the effect it creates is absolutely different.

Figure 35. Freeze frame from the contents displayed during the consumer panel.

Source: Late Motive (2017)

One of the points that was noted at our focus group was the change in the chroma of the image, all colors seemed burst, too explosive. Even in the television program, that does not have such a strict aesthetic purpose as the cinematographic content, this tool was rejected (78% with QLED and 60% with OLED).

Another important point to understand these results is the fact that we tested the tool with television content using a famous nightly talk show with a great amount of fans. These viewers are used to the specific aesthetics of the show, watching it every day, so when you suddenly turn the tool on the aesthetics change drastically causing the fans to reject it.

If we had tried the effect with television content broadcasted for the first time it would probably have received better acceptance, as in the cinematographic content.

If we had used a famous TV series, the rejection would probably have been worse since aesthetics are crucial in a TV series and great amounts of fans watch the series and are thus very familiar with the aesthetics.

Figure 36. Freeze frame from the contents displayed during the consumer panel.

Source: Valerian (2017)

A similar rejection happened with the cinematographic content (with a rejection of 58% for OLED and 51% for QLED).

Taking into account that this content was never broadcasted before (the viewers had no previous concept of the aesthetics of the audiovisual product). The results were very negative since, even with no preconception of the aesthetics of the film, they rejected the tool.

The only difference is that OLED was rejected more with this content than QLED but with no significant difference.

All the members at the focus group perceived the effect as a botched job.

10.1.4. Results

The HDR effect is supposed to adapt a regular SDR signal to an HDR one to be able to give more detail and information in highlights and shadows

As explained before, what the HDR effect tool does is to interpolate information from the original dynamic range in order to expand that one to get more information from dark and bright areas of the image.

This interpolation is very difficult to apply especially because it can modify the aesthetics, and this is exactly what happened, as was mentioned constantly during the focus group.

11. Combination of all parameters simultaneously

11. Combination of all Parameters Simultaneously

There is no doubt that the result of the perception of an image is actually a combination of all the different parameters that this research has gone through, acting simultaneously.

Thus, the perception of the dynamic range of an image is affected by the technology of the panel, the color depth is affected by the bit depth and the spatial resolution is affected by the viewing distance and so on.

This fact can lead to several confusions when trying to identify the elements that viewers prefer or those they dislike.

As we mentioned already in chapter 2, the parameters that affect the image quality and that will need to be modified in order to adapt the image to the different media are:

- Resolution (SD, HD, UHD, …)
- Scanning system (progressive or interlaced)
- Bit depth (8 bit, 10 bit, 12 bit, 14 bit, …)
- Color space (BT.601, BT.709 -covers 35,9% of the spectrum-, BT.2020 -covers 75,8% of the spectrum-)
- Contrast (100:1, 5000:1, …)
- Frame rate (24 fps, 25 fps, 30 fps, 48 fps, …)
- Refresh rate (60 Hz, 120Hz, 240Hz, …)

11.1. Panel technology and dynamic range

As a general rule, all viewers preferred the OLED technology over the QLED because of its black level performance; This leads us to understand the importance of black pureness for image perception, but this is not related at all to dynamic range: all images displayed were SDR; and only when testing the HDR effect tool did those images have an interpolated expansion of their dynamic range.

But since the results of the tool were dreadful (78% of the viewers preferred it off on QLED with television contents, 60% with OLED for the same contents and 51% of the viewers preferred it off on QLED with cinematographic contents and 58% with OLED with the same contents); This leads us to understand that it is the black performance only and not the expanded dynamic range that viewers clearly preferred.

What has been proved though, is that the black performance is key to the viewer's image quality perception and thus, native high dynamic range would be important too, since the HDR effect has been largely rejected with both QLED and OLED.

It all points out that the new technology to succeed would be one able to display the larger contrast ratio with native HDR contents.

Contrast ratio has been proved to be more important to viewers than any other feature, more important than spatial and temporal resolution, than expanded color space or LUTs. The only feature competing with contrast ratio in terms of image perception would be bit depth.

But HDR was designed to go together with other parameters that will reinforce its performance, such as a specific color space and bit depth.

11.2. Broadcast format and spatial resolution

As for the spatial resolution, it has been proved that, for a home TV set (up to 65'') it is not possible to notice any difference in resolution since the distance for the viewer to sit would be too uncomfortable in order to look at such a big screen at such a short distance. Therefore, there is no interest for the industry to keep investing in improving resolution since for visual acuity reasons and viewing distance it is not possible to enjoy it.

It is also important to note that the scaling process the panels apply in order to solve resolution disparities (explained in chapter 2, difference in resolution from captured content to broadcast content to panel) is an absolute success since all viewers preferred the scaled version to the native resolution for sport content using both technologies or didn't notice any difference for cinematographic content using both technologies (in this case, not noticing any difference is a positive point since it is a tool designed to solve a disparity and not to improve the viewer's experience).

Taking into account that most contents are broadcasted in HD according to BT.709 this is a very interesting feature from the panel, since it needs to scale it to 4K in order to adapt it to its own resolution.

Even though the scaling system of the panel is an absolute success, it is important to understand that, since most contents are broadcasted HD (some still SD) and we are not able to enjoy a 4K experience due to visual acuity and viewing distance problems, the best move for the industry would be to go back to HD panels instead of investing in increasing spatial resolution when most of the times viewers cannot tell the difference or prefer a lower resolution.

11.3. Bit depth and color space

It is broadly accepted by the industry that the wider the palette, the better, since this implies more color options. But the truth is that the bit depth is actually what determines whether we are going to perceive those options at the same time.

If we increase the color space without increasing the bit depth, we are changing the colors that we show, but we are not increasing the amount of colors; If we do the other way round, we do increase the amount of colors, although all from the same palette, the perception is of increase of color richness since we are showing more colors.

Therefore, these two parameters do not necessarily need to increase together, it is more important to increase color depth than color space since it affects perception more.

This has not been done yet for broadcasting reasons; an 8 bit signal takes much less bandwidth than a 10 bit.

11.4. Broadcast format, bit depth and image modes

If we think about the bit depth and the broadcast format, it is very simple for regular content, captured with a 12 bit depth, to end up broadcasted according to BT.709 with a shorter bit depth of 8.

In these contents the perceived colors are already less than what the filmmaker intended; In terms of image perception this is a very important point since the colors that were used to color grade the content will be different to the ones broadcasted.

After this process come the image modes; If after modifying the colors displayed in order to adapt to the normal (broadcasting regulations) we also add an image mode, what is left from the original footage in terms of looks is practically nothing. This leads us to watch the contents in an absolutely different way from the one the cinematographer, colorist and filmmaker intended.

According to them we would not be watching their content but something else. This current situation is clearly calling for a filmmaker mode to appear in the industry.

11.5. Scaling process, motion interpolation, image modes and HDR effect

As mentioned in the previous section, the contents that viewers end up watching can be absolutely different from the ones the professionals that created them intended.

We now bring a different point of view to approach the same problem.

If a content is broadcasted on HD, according to the BT.709, then scaled to 4K to adapt to the resolution of the panel (this is soon to be scaled to 8K), then its added motion interpolation probably at 240 Hz, then an image mode and finally the HDR effect, this is the outcome:

As explained in chapter 3, from the total amount of pixels that we see, 8,294,400, only 2,073,600 are original, and 6,220,800 are interpolated.

From the total amount of 240 frames that we watch per second, only 24 are original, 216 are interpolated.

If we then add an image mode or LUT to the content that will greatly modify the looks of the film (as explained in chapter 9, an image mode adjusts several parameters for this purpose such as contrast, brightness, color, tint, sharpness and color temperature).

Image 17. Same image with a LUT applied and without it.

Source: Smartfan

If we finally add the HDR effect that will try to expand the original dynamic range, there is little left of the original footage.

12. Conclusions

12. Conclusions

We will first expose the conclusion points related directly to our hypothesis and objectives, which show our global response to the study.

Our **first hypothesis** held true. Most of the elements that have so far been considered as crucial for the improvement of the image quality perception on a flat panel TV display are not crucial at all on these terms.

This hypothesis is now partially confirmed. The most prominent example of the confirmation is the importance given by the TV panel display industry to the increase of spatial resolution when we have seen that most viewers prefer to watch scaled versions over native or do not notice any difference. That happened equally with our focus group since resolution perception is based mainly on viewing distance and panel size.

Since human vision and viewing angles have their own limitations, there will be no contribution to the improvement of image quality in terms of human perception if the TV panel display industry keeps investing in spatial resolution increase.

Another example was the extra tools of the panel such as image modes and motion interpolation. In both, more than half of the sample preferred them off or did not notice any difference. In the focus group, all experts wanted them off by default, some even suggested that they should be completely eliminated.

When it comes to the image modes, this implies that, even with a new content (the test was carried out with the trailer of a non-released movie), where the viewers had no previous aesthetic reference, it was rejected.

As for the motion interpolation tool, it was preferred for content that it wasn't designed for and due to an unexpected reason: the change in the audiovisual aesthetics in new generations. This is the only point in which our hypothesis is not confirmed, for unexpected reasons and unforseen by engineers since the tool was designed for a different purpose.

These results call for a “filmmaker mode” as soon as possible.

As for the HDR effect, the results were clear: all viewers and focus group members preferred it off with both technologies.

Interpolators are now everywhere, in spatial resolution, in time resolution, in color accuracy. But dynamic range has made it clear that it needs to be native, from the capture of the content. Interpolating luminosity levels may not be as easy for algorithms to make it look natural or even realistic. Creating image information out of an image area where there is no image information is obviously too hard for any video processor.

Our **second hypothesis** held true: not all kind of contents require the same viewing tools from a flat panel TV display.

This hypothesis is fully confirmed. The most astonishing result in this matter being the preference from viewers to use the motion interpolation tool for cinematographic contents rather than for sport contents due to their age group. Also, the image modes which proved to be rejected by most viewers or not noticed at all.

Focus group members also unanimously agreed that all tools should adapt to the nature of the content and that consequently each content requires different tools.

When it comes to the motion interpolation tool, these results clearly come from a drastic change in the concept of aesthetics. The test was carried out with the trailer of the second season of one of the most specific aesthetic series in the last decade, *Stranger Things*.

The series takes place in the early-to-mid 1980s and follows every single cinematography aesthetic aspect of the period.

When applying the motion interpolation tool to such an aesthetically specific kind of content, all this cinematographic purpose disappears. It’s all washed out by the soap opera effect[lxvii]. This was what led the Duffer Brothers (the creators of the series), as explained in the state of the art, to launch a warning to the viewers on how to tune their TV sets in order to properly watch their series.

Nevertheless, all new generations appreciate it as something positive since it is closer to the new audiovisual aesthetics imposed through videogames as explained in chapter 8.

But this is certainly an effect that should be created on purpose by the cinematographer and not by a side effect of the flat panel TV display since most of the viewers will not even know that it is actually the panel itself that is creating the aesthetics.

We say side effect because, as mentioned in chapter 8, it is a tool that was specifically designed to watch sports but, comes on by default on the TV set.

In our survey[lxviii], the members of our consumer panel, when asked if their TVs had a motion interpolation tool, 71,1% of the sample responded that they did not know.

When asked if they ever adjust the image mode according to the kind of content they were about to watch, 65,2% responded no. 42,2% did not know if their TV set had image modes.

So, most probably, since a tool like motion interpolation still comes on by default in most flat panel TV displays, most viewers are watching all kinds of contents with that tool on and blaming the filmmaker when they do not like the cinematography.

Regarding the image modes, since most TV sets are sold with the dynamic or vivid image mode on (this is the preferred mode for shops since

[lxvii] Side effect resulting from watching fiction contents with the motion interpolation tool on that gives a new look to the contents where everything seems to be recorded on video instead of film.

[lxviii] See annex 2.

it saturates all colors and brightness values to draw the attention of the potential buyer over competitors in the same room) and, as the numbers on our survey show, 65,5% of TV users never adjust the image mode according to the kind of content they are about to watch, meaning that most viewers are always watching all kinds of contents with the image mode on.

Of course, this image mode was not design for films at all, but viewers would again blame the filmmaker for poor cinematography. The fact that not even the cinema mode was accepted or even noticed as a choice to watch cinematographic contents calls for a “filmmaker mode” to become available.

Our **third hypothesis** held true: the perception and appreciation of this quality depends on the kind of consumer in terms of visual perception and importance given to image quality.

Our **last hypothesis** is only partially confirmed. All focus group members did the same tests that we ran with the members of the consumer panel before attending the focus group and showed common results on their surveys after testing the different tools of the panel that were clearly differentiated from the ones from consumers. This was done to check their perception and not only their opinion.

All focus group members rejected the use of the extra tools (motion interpolation and image modes) and HDR effect and did not notice any difference in resolution.

A for the consumer panel, they did o’t notice any difference in resolution and rejected the HDR effect and image modes although some did like the use of motion interpolation for cinematographic contents (the younger age groups, as explained).

We thus see that consumers and experts only differ extremely on the acceptance of the motion interpolation tool. For the rest of the tests, their results match, even though the experts had more homogeneous results for all tests.

Our **first general objective** was; Know and disclose the opinions and criteria of flat panel display design professionals and cinematography professionals on the different factors that affect image quality on flat panel TV displays.

Thanks to the one-on-one interviews and the focus group, we were able to get a clear answer to this concern. To them, chroma, dynamic range and the respect for the filmmaker's decisions are the crucial points of importance in image quality, over other parameters like increase of spatial and time resolution.

Our **second general objective** was; Know and disclose the opinions and criteria of flat panel TV display design professionals and cinematography professionals on the question: do all contents require the same display tools?

In the focus group, the response was very clear: no, they do not. Each content requires different tools according to its nature. This answer led us to the first specific objective.

Our **third general objective** was: Study flat panel display design professionals and cinematography professionals' perception of the image quality on flat panel TV displays.

Before the focus group started, all focus group members took the same test taken by the consumers on the previous weeks. Their answers were all pointing in the same direction: reject the extra tools (motion interpolation and image modes) and HDR effect. No one noticed any difference in image resolution between HD and 4K.

Our **forth general objective** was: Study the perception of consumers of the image quality on flat panel TV displays.

Thanks to our consumer panel, we were able to test what viewers gave more importance to, what they notice or do not notice and what they liked or disliked.

As mentioned before, they all rejected the HDR effect and did not notice any resolution difference between HD and 4K (the most astonishing result here being the fact that viewers preferred the scaled version -from HD to 4K- rather than the native 4K).

They mainly rejected (most of the sample preferred it off or didn't notice any difference) the motion interpolation tool, but the youngest part of the sample did like the aesthetic effect created by it for cinematographic contents as explained in the results from chapter 8.

They mainly rejected (most of the sample preferred it off or didn't notice any difference with both technologies and contents) the image modes.

Our **first specific objective** was: Suggest technical solutions to allow both consumer and flat panel TV displays to identify the different kinds of content.

This technical solution was already suggested during the interviews and focus group and all members agreed on its usability and real need.

The task this tool will need to carry out is follow the protocol instructions on the label. It consists on creating a label system in order to broadcast all contents with their image quality specifications. Once the panel gets to read the label it only needs to adapt to what the label says and display the content according to its image quality specifications.

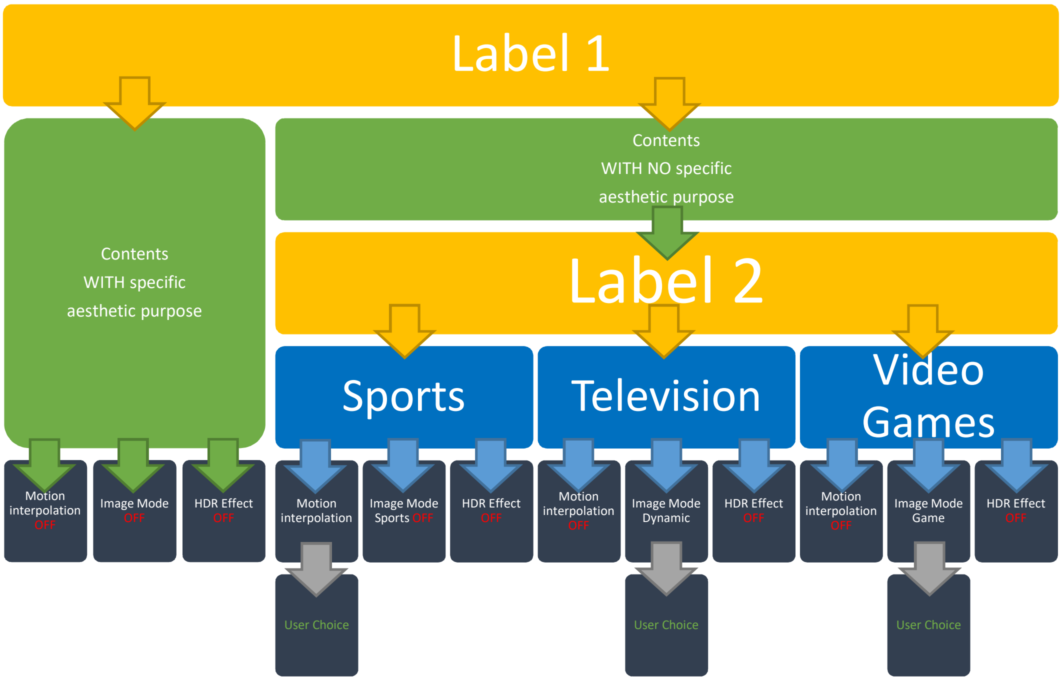
Example: The content will reach the panel with a label such as this one (this is already happening with metadata coming from VUI[lxix] and SEI[lxx] packets when the contents reach the panel).

[lxix] Video usability information.
[lxx] Supplemental enhacement information.

- Resolution: 1920x1080 pixels
- Scanning system: progressive
- Bit depth: 10 bits
- Color space: BT.709
- Contrast: HDR
- Frame rate: 25 fps

To this existing label we must add some specific information as such;

Figure 37. Suggestion of new metadata to include on flat panel TV displays.



Source: designed by the author

The panel will adapt to what the label's protocol and display the content with these image quality specifications in order to offer the best image quality experience to the viewer.

This process will be done by the panel by default and the user would be able to access other tools such as image modes or motion interpolation by navigating through the menu, but they would be switched off by default.

Also, each tool would include a short presentation video in order to explain to the user what this tool does and for which contents it is recommended (Most viewers at our consumer panel did not know what the tools were at all).

This label system is as basic as washing instructions on a garment, but it does not exist yet in the flat panel TV industry since it was not required before, but all new flat panel technologies would need to adapt to this increasing need.

Our **second specific objective** was: create a consultancy blog to inform users and manufacturers of the results of this research in order to provide them with tools that will allow them to choose their products with decision power.

This objective will not be done until this research is approved, but hopefully it will be of great interest for viewers and manufacturers to understand the needs of each other.

12.1. General conclusions

We have consequently reached four main conclusions;

There is no need for the flat panel TV display industry to keep investing in improving spatial resolution; Consumers do not need to look for flat panel TV displays with larger spatial resolutions.

The flat panel TV display industry needs to stop serving the product with the extra tools (motion interpolation and image modes) switched on by default; Consumers need to know what those extra tools are and how they perform.

The flat panel TV display industry needs to stop investing in HDR effect tools; Consumers need to look for native HDR contents on their content provider platforms.

The flat panel TV display industry should invest in creating a metadata system agreement to ensure that the image quality of the original content is preserved for the viewer; Consumers need to look for panels that include this new system or “filmmaker mode” option.

12.2. New investigation lines

This research has concluded that the need of a filmmaker mode system is needed in the industry, but this is just a starting point for the industry to reach a reliable system for measuring human perception of image quality. The next big step to explore being the new codecs generated from the different online platforms bringing on-demand contents to viewers on their TV sets.

This field has not yet been tested on human perception of image quality and is another aspect to take into account since its impact on image quality is enormous and leaves the viewer without means in terms of viewing options.

This area will have a lot of opportunities of improving image quality perception but needs careful testing before being released since a codec system accepted worldwide could result in a very difficult problem to solve once most receivers are using it.

12.3. Research Limitations

The main limitations of this research come from the error rate of our fieldwork. In order to have a 5% error rate we would have needed a sample of 384. That was not possible without University funding since this research does not belong to a specific research group.

Our error rate was 15% which is not desirable for any consumer panel; However, we consider that the conclusions coming from our fieldwork are solid and representative, even though the sample would have been more accurate with 384.

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14. Glossary of terms

14. Glossary of terms

Backlit panel: The main characteristic of a backlit panel is that it never turns its light off. There is always a light remanence at the back of the panel.

Bit depth: The video and image formats use discrete integer values to represent the luminosity level of each pixel. As a general rule, in the digital environment, a base 2 representation is used, where each digit is a bit and thus, the number of possible values to obtain on this base is of 2 elevated to the number of used bits. In digital video, the regular standard is 8 bits, which implies 256 possible luminosity levels per pixel. Nowadays video cameras can capture up to 16 bits. With the new 4K format, the 10 bits is the new standard.

BT.601: Standard recommendations from ITU for SD TV broadcast.

BT.709: Standard recommendations from ITU for HD TV broadcast.

BT.2020: Standard recommendations from ITU for UHD TV broadcast.

BT.2100: Standard recommendations from ITU for HDR TV broadcast.

Color Space: A specific organization of colors that relates colors to numbers in a three-dimensional form (X,Y and Z) that can form all possible color combinations within the gamut.

CRT: Cathode Ray Tube. Old non-flat screens. One of their main characteristics is that the lines displayed on a CRT are not appearing all at the same time but from left to right and from top to bottom first the even lines and then the odd ones filling the gaps.

Dynamic range: The difference between the darkest black and the lightest white of an image, the larger the dynamic range, the more different brightness values the image has. We can measure the dynamic range in f-stops on a camera or in contrast ratio such as 100:1 (100 being the white and 1 the black) on a panel or projector.

Emissive panel: The main characteristic of an emissive panel is that it creates the light it emits, it's not backlit, every pixel creates its own light.

Flat panel TV display: A flat panel TV display is a technology that was born in 1964 and arrived on the market in 1997. There are two different kinds of flat panel displays: emissive (plasma and OLED) and backlit (LCD, LED and QLED).

Frame rate: The number of different pictures or frames captured by the camera per second.

Full HD: Full High Definition. A TV format that defines the spatial resolution of images such as 1080p which means 1080 lines and 1920 pixels per line with progressive scan.

HD: High Definition. A TV format that defines the spatial resolution of the images with two formats: 720p and 1080i. The first format draws 720 lines and 1280 pixels per line with progressive scan, the second format draws 1080 lines and 1920 pixels per line with interlaced scan.

HDR: High Dynamic Range. An HDR image has around 17 f-stops of dynamic range.

Interlaced system: The interlaced scanning system draws the lines that form the picture on the screen in alternating fashion, first odd lines and then even lines from left to right from top to bottom.

ITU: International Telecommunication Union, founded in 1865. The ITU-R are the recommendations that the ITU has been launching throughout the years in terms of image quality and regulations for standards.

LCD: Liquid Crystal Display. A backlit flat panel display that uses polarizers and liquid crystals to make the stream of light reach the screen.

LUT: (lookup table), A color preset that does film emulation, cinema styling or other desired styles.

Motion interpolation: A form of video processing in which intermediate animation pictures are generated between existing ones by means of interpolation, in an attempt to make animation more fluid and to compensate for display motion blur.

NTSC: National Television System Committee. The analog television color system introduced in North America in 1954.

OLED: Organic Light-Emitting Diode. An emissive flat panel display whose technology is based upon diodes coated with a layer of organic components that, with a determined electric stimulation, emit light of a determined wavelength (color).

PAL: Phase alternating line. A broadcast television system for analog television used in most European countries and some of South America, Africa, Asia and Australia.

Plasma: An emissive flat panel display whose technology applies current to a rare gas to transform it into plasma gas. Thanks to the nature of plasma gas and the walls of the tube coated with phosphor, this results in visible light.

Posterization: This kind of artifact, also called banding, is most of the time due to an insufficient bit depth to accurately sample different color tone. The visual result in the image of this low sampling is abrupt changes of color tones looking like bands in the image.

Progressive system: The progressive scanning system draws all the lines that form the picture on the screen at the same time.

QLED: Quantum dots light-emitting diode. A backlit panel display whose technology uses small semiconductor particles that emit light of different colors depending on their size when current is applied to them.

Refresh rate: The number of times that the display device refreshes or draws the picture or frame on the screen per second.

RGB: Red Green Blue. Is an additive color system in which those three colors are put together in different manners to create a wide range of colors.

Ringing: This kind of artifact appears in the image as bands near the edges; they are incorrect parts of the signal that show in sharp transitions.

Scaling: A form of video processing in which by using an interpolation algorithm, the panel adapts the amount of pixels of the contents to its native resolution.

SD: Standard Definition. A TV format that defines the spatial resolution of the images that compose the video sequence in analog formats. In Europe, the PAL system establishes a resolution of 576 lines and 720 pixels per line. In USA, the NTSC system establishes a resolution of 480 lines and 720 pixels per lines. Both formats use interlaced scan.

SDR: Standard Dynamic Range. An SDR image has around 6 f-stops of dynamic range.

Soap opera effect: Side effect resulting from watching fiction contents with the motion interpolation tool on that gives a new look to the contents where everything seems to be recorded on video instead of film.

Spatial resolution: The number of pixels utilized to construct the image.

Temporal resolution: The number of frames displayed per second.

UHD: Ultra-high Definition. A TV format that defines the spatial resolution of the images with two formats: 4K and 8K. The first format, 4K, draws 2160 lines and 3840 pixels per line or 2160 lines and 4096 pixels per line. The second format, 8K, draws 4320 lines and 7680 pixels per line. Both with progressive scan.

15. Annexes

15. Annexes

15.1. Interview questions

1. In your opinion, which improvement to the image quality occurs when applying the motion interpolation tool of a flat panel TV display? How does it adapt to the different kinds of contents, sport, cinema, live shows, videogames…?
2. In your opinion, when watching images at a given resolution, if we need to scale them in order to adapt the receiving resolution (SD, HD, UHD, …) to the native resolution of our panel, are we improving the image quality? Does it make sense to watch an SD signal on a UHD panel with a x 16 zoom?
3. In your opinion, does the resolution of the panel need to be established according to the size of the panel in order to improve image quality? In your opinion, which maximum size would need to be established for each resolution?
4. In your opinion, should the signal dynamic range coincide with the native dynamic range of the panel in order to improve image quality? Are the tone mapping techniques efficient at adapting the video format from SDR to HDR?
5. In your opinion, which adjustable parameters on current flat panel TV displays are the most important in order to improve the user's experience in terms of image quality?
6. In your opinion, which kind of panel lighting contributes best at improving the flat panel TV display user's experience in terms of image quality? Explain your answer.
7. In your opinion, do image modes (present nowadays in almost any flat panel TV display device) always improve the user's experience in terms of image quality? Explain your answer.

8. Do you have data regarding which adjustable parameters users manipulate most? Do you have data regarding if they do this according to the kind of content they are watching?

15.2. Survey

CEU Universidad San Pablo

Encuesta de valoración de calidad de la imagen

Edad:

Sexo:

País de residencia:

¿Tiene TV en casa?

☐ SI ☐ NO

¿Con qué periodicidad ve su TV?

- ☐ Todos los días, más de dos horas
- ☐ Todos los días, unas dos horas
- ☐ Todos los días, alrededor de una hora
- ☐ Todos los días, menos de una hora
- ☐ Alrededor de tres veces por semana
- ☐ Alrededor de una vez por semana

¿Cuál es el tamaño de su TV?

☐ 32”	☐ 40”	☐ 43”
☐ 48”	☐ 49”	☐ 50”
☐ 55”	☐ 65”	☐ Otros
☐ No lo sé		

¿Cuál es la tecnología de su TV?

- ☐ LCD
- ☐ Plasma
- ☐ LED
- ☐ OLED
- ☐ QLED
- ☐ Otros
- ☐ No lo sé

¿A qué distancia observa su TV?

- ☐ 1m
- ☐ 1,5m
- ☐ 2m
- ☐ 2,5m
- ☐ 3m
- ☐ Otros
- ☐ No lo sé

¿Qué tipo de contenido consume con mayor asiduidad?

- ☐ Deportes
- ☐ Cine/series
- ☐ Programas de TV
- ☐ Videojuegos
- ☐ Otros

¿Qué modos de visionado tiene su TV?

- ☐ Estándar / juegos / vivos / naturales / deportes / cine
- ☐ Estándar/juegos/deportes/cine
- ☐ Otros
- ☐ No lo sé

¿Los ajusta en función del contenido que está viendo?

- ☐ Sí, siempre
- ☐ Alguna vez
- ☐ No, nunca
- ☐ No sé si mi TV tiene distintos modos de visionado

¿Ha ajustado alguna vez los controles básicos de su pantalla? (brillo, contraste, detalle, …)

- ☐ Sí, muy a menudo
- ☐ Sí, alguna vez
- ☐ Una vez
- ☐ No, nunca

¿Ajusta la iluminación de la sala para ver el TV?

- ☐ Sí, siempre
- ☐ Ocasionalmente
- ☐ Casi nunca
- ☐ Nunca

¿Ve contenidos en su TV por medio de un ordenador/tableta/teléfono?

- ☐ Sí, por HDMI
- ☐ Sí, uso Chromecast
- ☐ Sí, por VGA
- ☐ No, nunca

¿Ve contenidos desde distintas plataformas de TV? (TDT, fibra/ADSL, satélite, …)

- ☐ Sí (Especifique cuáles):

- ☐ No

¿Qué contenidos considera que se ven con más calidad y desde qué plataforma?

¿Tiene su TV opción de interpolación de movimiento (Trumotion, Smooth motion, Motionflow, Auto motion plus)?

- ☐ No lo sé, nunca me he fijado
- ☐ No, no tiene esta opción
- ☐ Sí, la tiene activada por defecto, siempre veo todos los contenidos con esta opción
- ☐ Sí, la tiene, pero siempre la tengo desactivada
- ☐ Sí, la tiene, pero solo la utilizo para ver contenidos deportivos
- ☐ Otra (especificar):

Visionados

¿Cuál de los visionados le ha gustado más en lo que a calidad de la imagen se refiere?

Contenido	1º	2º	No he notado diferencia
A	☐	☐	☐
B	☐	☐	☐
C	☐	☐	☐
D	☐	☐	☐
E	☐	☐	☐
F	☐	☐	☐
G	☐	☐	☐
H	☐	☐	☐
I	☐	☐	☐
J	☐	☐	☐
K	☐	☐	☐
L	☐	☐	☐