Mobile Cameras in Professional Video Productions

The state of the art of mobile device cameras
and their image quality compared to broadcasting standards

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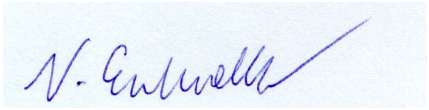

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Abstract

There are already many papers that discuss the role of DSLRs in filmmaking, as it was a game changer for professional film production, not only by offering more affordable cameras but also introducing different ways of storytelling and cinematography. Various books teach how DSLRs are best used and set up to make the most out of their characteristics. This paper aims to take it one step further and explore what mobile devices can offer in these aspects. Therefore it will take a look at current camera phone specifications, specifically the iPhone, since Apple has dominated the mobile device market and their products are commonly used for professional video productions that work with phone cameras.

This paper will also introduce different systems of measuring image quality and which parameters are important for mobile camera. Based on that there will be a part on how to measure and compare them. A comparison between the iPhone 7 and a common Broadcasting standard will be made to see how the mobile camera holds up against defined quality standards.

Furthermore it will introduce productions that have successfully used mobile devices as their main camera, showing what advantages they provided and what aspects the filmmakers struggled with. A segment about Apps and gear developed for mobile phones will give a short overview on how these Gadgets can improve the capabilities of the phone and broaden the possibilities for the user.

Table of contents

1 Introduction

Photos and videos are everywhere and they just become more and more. It's estimated that 1.2 Trillion digital photos have been taken in 2017. 80% of these with mobile devices and the numbers grow about 9% every year. But with the amount of photos growing so does the amount of videos. Not only do these videos get produces en masse they also get watched a lot.
As mobile devices as camera gain popularity they start getting integrated in professional video productions. Their easy handling, cheap price and small proportions make them ideal to use for original angles and perspectives, whether it be for multicam production, sport events, multimedia gimmicks in tv shows or even as the main camera for films.
("Here's How Many Digital Photos Will Be Taken in 2017 - True Stories.") More and more productions are looking towards mobile devices to use as storytelling and production tools. Because there's nothing these small tools can't do, right?

But all professional productions have a certain standard and quality level they aim for. Many production companies have their own production standard, videos have to have a certain resolution and quality for different platforms, and broadcasters have their delivery standards. Even though cell phone cameras are already commonly used it is unclear whether they fulfill the standards of professional productions. To get a perspective on how far digital device cameras have been developed this paper investigates the following question:
Does the video output of iPhone cameras conform the HD broadcasting standards and how can it be optimized?

As technology advances filmmaking gets more and more accessible to the public. Super 8 film was the first step in bringing film technology into the consumer's homes. While it was not comparable to professional film formats the field is changing now. Digitalization made filmmaking cheaper and the gap between professional productions and amateur projects is getting smaller.
With the introduction of the video function on DSLR cameras it was suddenly possible to recreate the typical cinematic look with a very small depth of field with much cheaper and smaller cameras. DSLR systems offered new creative approaches due to their lightweight and unique look. Even professionals started to use the cameras for high end productions and they are now commonly used in the industry.
With mobile devices now offering high definition video capture, the improvement of sensors and digital data processing we reached yet another peak in the area of cheap and fast filmmaking. Even iPhones are already able to film videos in 4k now, a trait that many professional cameras still lack today. There are already film festivals devoted to mobile video only all over the world. While the quality of these devices used to be frowned upon a few years ago, not only the improvement of the built-in camera itself convinced industry professionals to consider using mobile devices, but also the development of lenses, steady cams and especially applications that make it possible for the user to manually control aperture, light temperature, focus and many other parameter of the video. For most aspects the video function of mobile devices lacks there is already some hard- or software out there.

With the proper setup it is possible to create cinema like videos from an iPhone. There have been professional advertisement or whole feature films, that were filmed solely on mobile devices. The most notable is “Tangerine” which is said to be one of the best films of 2015, getting outstanding reviews at the Sundance film festival. An example like this proves that from the audience point of view mobile device produced movies are able to compete with films that are shot on professional high end cameras. However one has to consider that the visual aspect of video has always had more freedom in quality aspects than other production components like audio, and good audience reception does not always align with technical quality. An example would be the horror movie Paranormal Activity(2007), which was shot on a Home Video Camera. The poor image quality supports the story that is told and makes it feel for real. The same effect happens when cell phone videos show up in the news, which might be blurry and hardly recognizable, but still give the viewer a stronger impression of watching something real than a professionally recorded video. However this paper does not focus on the style of the video, but rather on the quality that can be achieved with the mobile device cameras. As there are many factors that could an image be considered good, objective standards that can be measured and compared are necessary to answer whether mobile device cameras can compete with professional cameras.

2 Professional use of iPhone cameras

“Most of all, visual journalism is about quality. It’s about creating remarkable non-fiction stories that resonate with audiences, surprise and entertain, and connect people to distant, complex issues.” (Trofin, “The Rules Remain the Same.”)

Especially when shooting documentaries, mobile devices can improve the whole production process. As people behave in a certain way as soon as they spot a professional camera team, most cultures are used to civilians taking photos and videos on their smartphones by now. In situations or countries that might be difficult or even dangerous to journalist having a small phone can be incredibly helpful, as it blends in and does not attract unwanted attention.

Another aspect mobile phones provide is that they usually adapt their settings automatically according to the situation. While this might trouble professional filmmakers, it can highly improve a video journalists work when things have to happen in a matter of seconds and there is no time to change the settings manually. One could even further explore the programming of apps to work with certain presets that can be applied according to what is currently needed to save time and automate a process, while still keeping up a good video quality. Which could make the camera assistants work much easier.

As the quality of mobile device cameras kept improving, so did the possibilities to share the video results. Many video platforms and Apps helped mobile videos gain popularity. While some platforms are only used for entertainment, like “Vine” did before it shut down in 2017 or Snapchat where communication works via photos, other are more keen on putting out higher

quality content. Many instagram profiles are dedicated to creating pretty photos and videos. The video sharing platform vimeo even has a channel that only focuses on short films shot on iPhones. Not only is a mobile phone cheaper and easier accessible, there is also the fascination to see how much one can get out of such a small device and how to push it to its limits. Even though it lacks many characteristics that are considered important for a professional film camera, experimenting with alternative methods challenges the filmmakers to find new unique ways of storytelling. The channel can be found here: https://vimeo.com/channels/iphones

Figure 1. Scene from Sean Bakers film Tangerine

One of the biggest hits in cell phone filmmaking is the Sundance 2015 hit “Tangerine”. Radium Cheung, the director of photography for Tangerine, which was entirely shot on an iPhone 5S, was not excited about having to shoot on a mobile device first as it has very limited control. The production used MoonDogLabs anamorphic adapter and the Filmic App to create a more cinema like look and have better control over the settings. The choice to use iPhones was made primarily for financial reasons, but later proved valuable for storytelling aspects as the film has many documentary traits and was filmed in public. Due to the crew working with such a small device civilians would not take them seriously and just walk by. It was easier to blend in and move around freely for the camera team. (Baker, “Tangerine Making-Of”)

One of the bigger issues when using very small scale cameras like the ones built into iPhones is the size of it. Due to the small lense and sensor every bit of movement translates even bigger into the video. While the iPhone has a very good digital stabilizer it does crop the image in order to do so. A good stabilizer or steadicam for the phone itself will help to create a smoother look. The lightweight iPhone can be combines with many affordable gadgets that will make it possible to use in ways that would be more difficult for classic cameras. While professional cameras require a dolly for a smooth dolly move a iPhone attached on a stabilising system can be simply held in one hand while driving on a bike for example. Underwater covers for mobile devices are

much smaller and inexpensive. And due to the size phones can fit into places regular cameras would have no access to, which allows for new perspectives and ways to frame a scene.

There were other benefits to using an iPhone. Nonprofessional actors like his leads usually need time to get used to a camera. But because everyone is familiar with an iPhone, the cast felt comfortable from the beginning.(“Sean Baker Talks ‘Tangerine,’ and Making a Movie With an iPhone - The New York Times.”)

“We’re at such an early stage of using devices that aren’t cameras to make films, that you can do whatever you want. We just experimented. And we just said what benefits can be found here.” Sean Baker, director of Tangerine. (Film Courage, *iPhone Filmmaking Advice by TANGERINE Filmmaker Sean Baker*.)

But Tangerine was not the first feature shot purely on a mobile phone. Also using Apple products, the movie “Uneasy Lies The Mind” was shot on the iPhone 5 in 2014. Ricky Fosheim directed, shot and produced the movie on a very small budget for which the iPhone was a good choice. As the story is set in winter he describes the short battery life of the phone as one of their biggest issues. ‘A fully charged iPhone 5 will die in less than two minutes when exposed to these frigid cold temperatures. In between takes the filmmakers would have to place the camera underneath their armpits in order to keep it warm. Numerous takes were lost because the camera would continuously die mid-shot.’, he states.
(“iPhone Used to Shoot Entirety of Feature Film Uneasy Lies The Mind | Daily Mail Online.”)

ABC’s TV show Modern Family created an entire Episode called “Connection Lost” on Apple devices in 2015. Cleverly using the devices as storytelling tool, the episode centered about the sitcom’s characters interacting through a series of FaceTime(an App for video calls, like Skype) calls. The crew solely used iPhones, iPads and MacBooks to create all the footage. Even with the seemingly high limitations the devices and the choice to make all footage Facetime calls they created an intriguing Episode with great cinematography.

One of the most demanding discipline in video production are probably commercials. In 2015 Apple shot their own iPad Air 2 advertisements for the Oscars and the Grammy Awards on the iPad Air 2. While is was a clever marketing choice to shoot a commercial on their own device, Apple also collaborated with automaker Bentley to produce a car commercial. The three minute ad that was shot strictly on an iPhone 5s. The look and feel was greatly enhanced by the use of additional gear like a BeastGrip lens adapter, a Neewer Fisheye lens, MoVI M5 gimbal stabilizers, and a Schneider iPro lens. Like many productions they used the FiLMiC Pro App to have more control over the camera’s settings. (Stella, “12 pro-Caliber Videos You Won’t Believe Were Shot on an iPhone.”)

3 Setting a Standard

In order to measure something and compare it one has to decide what to measure and to what it should be compared. There are thousands of different production requirements out there and they can vary for every single production. Some could be as simple as requiring 4K footage, others could be incredible detailed and technically complex in every production aspect. This paper only looks at the video recording aspect, and only considers the context if it has an impact on the image quality or standard that is required.

As streaming and film requirements often vary heavily and delivery requirements for commercial videos are completely dependant on the needs of the client, broadcasting is the area of video production with the most unified and definied video standards. This is the reason a broadcasting standard was used to evaluate the mobile devices camera quality.

HDTV Standards

To answer the research question it is important to define a specific broadcasting standard. This thesis will look specifically at the delivery and production standard of the European Broadcasting Group ARD, ZDF and ORF.

The basis of this standard are the technical parameters set in the EBU-TECH 3299, which is the European HDTV standard. These are defined in the video standards SMPTE 274M and SMPTE 296M, as well as in SMPTE 292M for HD-SDI.

If a program is produced for HD it should continuously be filmed in HD.
The two defined formats are:

XDCAM-HD422 mit MPEG-2, 4:2:2, long GOP, 50 Mbit/s,
P2 with AVC-I 100, 4:2:2, I-Frame, 112 Mbit/s (SMPTE RP 2027).

In “Technische Richtlinien - HDTV zur Herstellung von Fernsehproduktionen für ARD, ZDF und ORF” there is a section regarding special uses, including videojournalism that refers to HD low cost and consumer formats. These should only be used when chosen for unique visual and creative traits, or for acquired material by the broadcaster only, like videojournalism and reports from critical areas.

The paper also covers what defines a camera as mainstream and usable for the broadcasters programs. While most mobile device cameras do not fulfill these specifications, like a ⅔” sensor they are still used for many productions. But technical specs like the sensor size does not necessarily relate to poor image quality, as there are many processing techniques that can offset the disadvantage, which is why this thesis wants to take a deeper look on how the final

product compares, independent from which camera it was produced with as long as it fulfills the delivery standards.

Based on the functional specification sheet of the german broadcasters the following specifications should be complied:

Recording format: **1080p/50, 720p/50**
Subsampling: **4:2:2**
Sample Frequency: **min. 3,375 MHz**
Camera Sensor: **min. 2/3 “**
Native Size: **1920 x 1080 pixels**

Colorspace(RGB)

HDTV: **E’Y = 0,212 E’R + 0,715 E’G + 0,072 E’B (ITU-R BT.709)**
Dynamic Range: **14 f-stops**

Image Center

Vertical: **between line 581 and 582 (full image is 1125 lines height)**
Horizontal: **between line 959 and 960 (full image is 2200 lines wide)**

Important Image Part should be in the area of

Vertical: **line 80 to 1083**
Horizontal: **line 67 to 1852**

The following artifacts should be reduced as much as possible
and should ideally not happen at all:

Noise, especially in darker images
Grain
Rolling-Shutter
Alias-Effect / Moiré-Patterns

The guidelines also include specifics for Audio, which will not be considered in the comparison, as it would burst this paper. This decision took in account that even though there are already professional tv-productions, commercials and films that have worked with mobile devices to record video, most of them have used professional audio equipment to record the sound separately and synced it later with the video.

As there are already Codecs with the efficient H.264/AVC and H.265 compression available which are already introduced by the Eurovision Satellite Network of the EBU, HD profiles for these formats got defined.

4 Measuring and Parameters

After defining the minimal technical video and camera properties it is important to define how to test and compare those. While a few aspects can be concluded just by looking at the technical specs of the camera others need practical camera tests.

Due to the popularity of mobile devices as camera and video tool in the public there are many discussions on what makes a good phone camera and a huge variety of camera tests that show comparisons between different models and brands.
Most of these tests do not follow established criteria and usually just portrait various situations and look at the results subjectively. They are done by independent individuals or reporters who publish them on internet portals or blogs. This gives little to no information of the technical and objective quality of the image. There are currently three known ranking systems that try to unify cell phone camera quality tests, two of which provide rankings to the public themselves.

The most prominent one is IEEE's cellphone image quality group (CPIQ), which is constantly working on publishing and updating their standard white paper for camera phone tests. The group launched in 2006 and consists of over 20 key players of the mobile phone industry. Their main goal is to create a standardised evaluation method for phone cameras that can be used by all cell phone producers. By regulating the testing methods the results will be unified and technical specs will be more relevant as they can be compared directly with other devices. They also aim to remove poor image quality and make the phone cameras more attractive for the consumers, which would encourage them to a wider use of the cameras. Not only does the CPIQ aim to unify the testing methods, in order to properly compare the results they also try to create an universal use of the same measurement techniques and specifications. While they are ("I3A Publishes Camera Phone Image Quality White Paper.")

The CPIQ group mainly focused of creating a rating standard that can be used by the whole industry alike, but focuses little on testing the devices themselves. VCX gives a good example of using charts to define the image quality, DxOmark mainly tests the cameras through practical use and gives a detailed comparison of the images look to the viewer while still taking graphs and scopes in account.

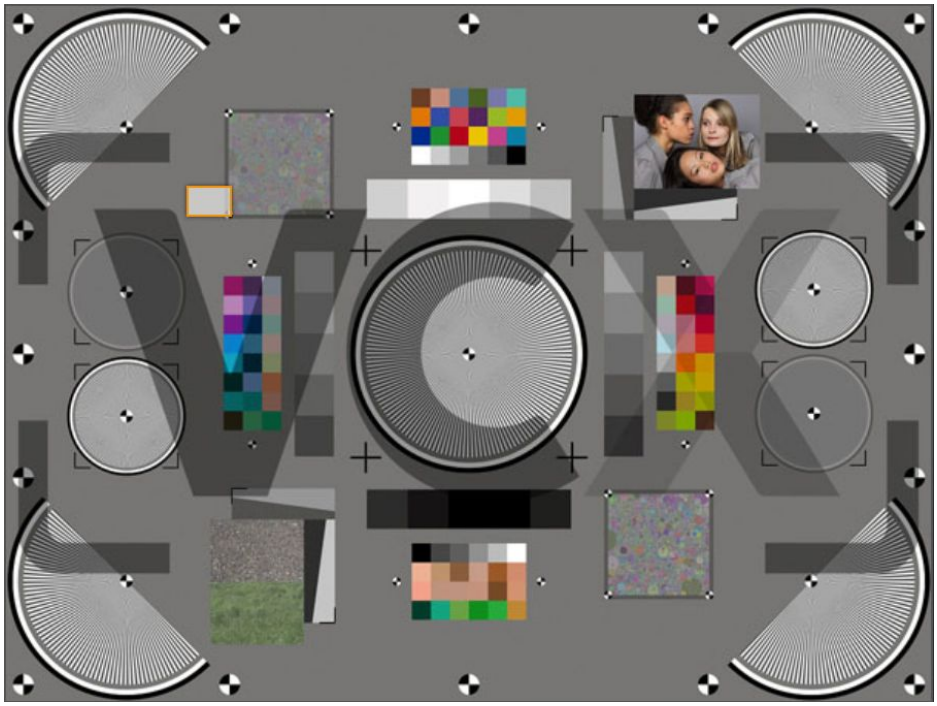


Figure 2. VCX uses known charts to rate the mobile cameras capabilities.

Dietmar Wueller discussed the different rating systems in his text “Cell Phone Camera “Rankings”!” and describes the common aspects that define image quality.
In order to measure image quality the following factors can always be applied:

- Exposure (ISO 12232)
- Dynamic range and noise (ISO 15739)
- Detail Reproduction (resolution) (ISO 12233)
- Sharpness / Acutance (lens performance) (ISO 12233)
- Optical aberrations like distortion (ISO 17850), chromatic displacement (ISO 19084), shading (ISO 17957), flare (ISO 18844) etc.

Considering the huge amount of processing involved after capturing the raw data with mobile phones he also adds the following attributes:

- Color (color reproduction) including chroma level and preferred color rendering
- White balance
- Sharpness /Acutance (added sharpening)
- Tonal Rendering
- Texture (low contrasts in an area without a certain pattern) (ISO 19567)
- Color shading (ISO 17957)

The ISO articles further describe the standardized definition of these terms.
While all of these aspects are important, it is also important how they play together to create a balanced image. In case one of them completely fails the test, it will lower the final score

significantly. Therefore it is hardly possible to provide a final result without having tested every single aspect, as proficiency in almost all of them could still be offset by a low result on another.

While DxOMark and VCX tests the cameras in many different situations, motive as well as light wise, they do not do any psychophysical studies at all. While the test results can look good on a scope or run through an image analysing program like imatest provides, it always depends highly on the context and what the image is supposed to achieve. CPIQ has a high priority on performing psychophysical studies along with technical tests. When they did a study for saturation it turned out that the optimum value depends lightly on the scene and that most people prefer abou 10% higher saturated colors.

Psychophysical tests are a very time consuming and expensive technique as they have to follow exact viewing conditions and provide enough participants to have a significant result. CPIQ defined the test to be conducted looking at a 100 Ppi Monitor from 864 cm distance and the images being displayed in 100% mode meaning 1 pixel in the image corresponding to 1 monitor pixel, based on ISO 20462-3. (Wueller, “Cell Phone Camera ‘Rankings’!”)

Most of these concepts focus on the image quality when taking photos, while a common test standard for video recorded with mobile devices is still lacking. When recording video factors like frame rate, rolling shutters and how the device deals with changes and movement become very important. These aspects are not even considered in most image quality tests for cell phones and others need to be viewed front he video perspective like the shutter speed, which cannot be as freely changed as in photography. Even data rate and file formats can affect the image of the video stronger than they would a single taken photo. DxOMark does video tests and includes a rating for the video features but usually does not go much into detail for these points.

The algorithms behind cell phone videos are one of the greatest advantages of these cameras as they can make images look good very quickly without having to grade them on post-production. It is also the aspect that limits the professional production aspect the most and is the hardest to deconstruct. While Apps like FiLMiC Pro try to avoid these algorithms and make as many settings as possible manually configurable by the user, even these apps struggle to completely avoid them. A good example would be the zoom function. While there is a 5x optical zoom available it is still the cell phones algorithm which picks whether the optical or digital zoom should be used in a certain situation.

5 Apps and Gear

Figure 3. FiLMiC Pro menu

FiLMiC Pro - 14.99$ per month

(http://www.filmicpro.com/)

The App FiLMiC is available for iOS and Android and the company states it “turns your iOS camera into a broadcast worthy High Definition video camera.” It provides the user with manual control over focus, exposure, ISO, shutter speed, tint and color temperature. It also features various aspect ratios, grids, resolutions, variable speed pull focus and variable speed targeted zoom, as well as manual control over audio settings and monitoring. The lack of manual control over these settings is often what differentiates consumer product to professional equipment.

It is the most popular app in the field and has been used for almost all productions mentioned in previous portions. It is noteworthy that during a psychophysical camera test, with help of FiLMiC Pro the iPhone tied with the much acclaimed Canon C300 and beat the Sony FS100 camera.

Figure 4. Log settings on FiLMiC Pro

Filmmaker Pro - free

(http://www.filmmakerproapp.com/)

While not as popular and reliable as FiLMiC Pro, Filmmaker Pro is a good and free alternative to the mobile phone app. It features similar options like 3D touch quick action, manual exposure, shutter speed, ISO, focus and white balance controls. The handling, scroll and steppers system is inspired by DSLR cameras. The video resolution and frame rate is manually adjustable, and it provides options for audio leveling and supports external microphones. It also has stabilisation and Metadata features.

Apart from these two apps there are various others that can support the recording process, but they are not widely used as FiLMiC and Filmmaker already provides a very cheap and advanced service.

1.33X Anamorphic Adapter Lens - for iPhone 7 - MoonDogLabs - 175$

(https://www.moondoglabs.com)

Even though there are multiple lens adapters on the market the most notable one is the Moondog Labs 1.33X Anamorphic Adapter. It is the tool that actually made filmmakers consider the iPhone as a cinematic tool. The adapter enables wide format imaging with organic flares and distortions that create the popular “film style”, which is softer and has less depth-of-field than the regular phone image that is crisp and oversharpened. It preserves the full resolution of the iPhone camera while creating 2.4:1 aspect ratio video and panoramic 16:9 still images. Baker, the director of Tangerine said the following about the lense adapter, when being interviewed for The Verge: “To tell you the truth, I wouldn’t have even made the movie without it.” It elevated the film to a cinematic level for him.

Another lens adapter is the **EnCinema 35mm Lens Adaptor(189$ from mCAM)**, which focuses even more on creating the small depth-of-field look. For effects there is also the Neewer

Fisheye lens. Aside from many more apps and lens adapters there is a huge variety of tripods, stands, arms and stabilizers. As useful they are and even though they provide many opportunities that would be lost on conventional camera, their impact of the video is not as grave except for the stabilizers.

6 Technical Specifics of mobile device cameras

When looking at the websites of DxOMark and VCX it quickly becomes clear that Apple products are not quite the top tier when it come to image quality. With a constant flow of new mobile phones on the market the competition is high and just keeps improving. Still, this paper will only focus on the iPhone series.
The decision to use the iPhone series for comparison and camera tests was made, due the wide possibility of add ons that are available for Apple products. While some Apps that give the user more manual control over the recording are available for Android phones, the majority of Apps that expand the cinematic possibilities of mobile phones are optimized for iPhone.
Even more so when it comes to Hardware like lens adapters, stabilizers and other Gadgets that improve the production. Furthermore most professional video productions that are known for using mobile devices used Apple products. The iPhone is the most popular phone on the market and clearly dominating the professional use of mobile cameras, as all the previous examples where shot on Apple devices.

Recent iPhone models:

iPhone 5, September 21, 2012
iPhone 6 (Plus), September 19, 2014
iPhone 7 (Plus), September 16, 2016
iPhone 8 (Plus), September 22, 2017
iPhone X, November 3, 2017

During the work on this research paper two new iPhone models and countless other mobile devices were introduced. Technology in this field is constantly improving and this is a mere look at the state of the art and a comparison whether the cell phone cameras have already reached professional quality and if not what is still missing to get them there.

iPhone 7 Camera Specs

- 12MP wide-angle and telephoto cameras
- Wide-angle: f/1.8 aperture
- Telephoto: f/2.8 aperture
- Optical zoom up to 5x
- Digital zoom up to 10x
- 4K video recording at 30 fps
- 1080p HD video recording at 30 fps or 60 fps

- 720p HD video recording at 30 fps
- Optical image stabilization for video
- Optical zoom; 6x digital zoom (iPhone 7 Plus only)
- Quad-LED True Tone flash
- Slo-mo video support for 1080p at 120 fps and 720p at 240 fps
- Time-lapse video with stabilization
- Cinematic video stabilization (1080p and 720p)
- Continuous autofocus video
- Body and face detection
- Noise reduction
- Take 8MP still photos while recording 4K video
- Playback zoom
- Video geotagging
- Video formats recorded: HEVC(H.265) and H.264

(“iPhone 7 - Technical Specifications - Apple.”)

7 Comparison and Tests

iPhone 7 specs vs. Broadcasting Standard

As the previously established broadcasting standard focuses mainly on the technical specs of the production many points can be resolved by just comparing them with attributes of the iPhone. With the phone camera going up to 4k and the FiLMiC Pro App offering a huge variety of file formats and the possibility to choose the subsampling rate the points recording format, subsampling and native size are already in favor of the iPhone 7.

While the iPhone offers H.264 and H.265 formats, Apps like FilmicPro offer less compressed options, with the Filmic Extreme format almost reaching RAW quality. It also gives the user the option to choose their own subsampling rate.

Apple does not officially state the sensors they used in their product specifications. However the CMOS sensors in Apple products are usually provided by Sony. While the iPhone 6 has been using the Exmor RS IMX135 model, a type 1/3.06 with 13.13 effective megapixels.

It is said that the iPhone 7 uses the Exmor RS IMX230 sensor type 1/2.4 with 21 effective megapixels, as it correlates with the features and megapixel Apple provided for its product.

Specs of the **Sony Exmor RS IMX135**

Number of effective pixels:	4208(H) x 3120(V) 13.13M pixels
Frame rate:	Full, 24 fps, 30 fps, 15 fps
	1/2 sub sampling, 48 fps, 60 fps, 30 fps

	1/8 sub sampling, 120 fps
HD mode,	1080p, 30fps (HDR mode)
	1080p, 60fps
	720p, 60fps

Specs of the **Sony Exmor RS IMX230**

Number of effective pixels:	5344 (H) x 4016 (V) 21 megapixels
Frame rate:	Full, 24fps
	4K(4096 x 2160), 30fps
	1080p, 60fps
	720p, 120fps

The sensor size is one of the most important aspect of the camera. Larger sensors can capture more light and can work in darker lit scenes. As phone cameras are so small their sensors are only fractions of an inch. Jumping from the 1/3" sensor of the iPhone 7 to the bigger 1/2.4” sensor of the iPhone 7 was great improvement as many other smartphone developers have used bigger sensors way ahead of Apple.

Considering the broadcasting standards that require production cameras to have at least a 2/3” sensor, all mobile phones cameras would already fall through. However the Broadcasting Standards includes the clause for special uses and for unique visual and creative traits, which could applied for many situations where mobile phone cameras come in handy.

While the iPhone sensor is quite smaller compared to other mobile phones, it is still one of the most popular mobile devices to use for filmmaking. iPhones have the advantage of a huge number of Apps and gadgets that can improve the video quality drastically. Apple stated at the iPhone X release that the new phone can capture 83% more light than its predecessors, which could suggest a bigger sensor size, but has not been officially confirmed.

Since the iPhone 7 model Apple has been sticking to the concept of using two camera lenses instead of one. Having two different lenses, one wide and one a telephoto lense, enables an optical zoom with the telephoto lens. However this function is not manually controllable. When using the zoom function an algorithm decides whether the image would work better with optical or digital zoom. The regular lens is equivalent to a 28mm length and the telephoto 56mm. (“iPhone 7 Plus 2x Zoom Isn’t Always Optical – for a Reason.”)

8 Practical Camera Tests

The camera tests were done with an iPhone 7 in a studio. Three different charts were positioned in front of a grey wall. Two kinoflows with four 3500K lamps each were set in 45° on both sides of the chart. The distance to the chart started at 3 feet and was increased for lower light levels. The iPhone itself was attached to a C-Stand facing center onto the charts. As the iPhone itself

has nothing to attach it to a tripod or a stand this was the first challenge. While there are many Selfie sticks and stabilizers into which the iPhone can easily be set into there are little Gadgets to simply attach it onto a tripod and keep it in a fixed position. Due to it being the simplest and most cost effective solution the iPhone was carefully fixed in a grip handle, cushioned by thick cardboard so the phone would not get damaged. This solution unfortunately resulted in about 5% of the screen not being visible, which was acceptable as it did not affect the tests. A production wanting to use a mobile device on sticks should rather refer to products like

As Dietmar Wueller discusses in Cell Phone Camera “Rankings”!” conducting exact and comprehensive camera tests it a very time consuming and expensive matter. Doing a full image quality test like it was outlined by the CPIQ would have burst the extend of this paper, therefore a few image aspects we're selected to be tested in the available environment.

As this paper wants to compare the video quality of the iPhone with the standards of HDTV in Austria, Germany and Switzerland all camera tests that have been performed for this paper were done in the most widely used TV format of 1080p/50 as it is common practice to record video in the same format is should be delivered to avoid transcoding footage and varying formats, as it can save a lot time in post-production and unify all the material available.

All recordings have been made with the FiLMiC Pro App, as the goal was to test the limitations of the cameras and their sensors themselves, rather than the final video result after it went through algorithms and encoding of the regular camera app. Even with the FiLMiC Pro App it is impossible to get a completely raw video result, but it does provide the option to record in less compressed formats and even shoot in Log(detailed information about their Log Option can be Found in the FiLMiC Pro Log Whitepaper). Log means that it will not apply any image profiles to enhance the look inside the camera. Rather the video will be saved as the sensor views it. When recording in a high quality with little compression enough data is still available to correct the image later in Post-Production and usually leaves more options, as when the image profile is already applied. FiLMiC Pro still does not achieve full raw, but is the closest one can get at the moment with the apps available on the market.

It is important to use known targets when testing cameras as otherwise there would be no set values to compare the output to. This is one of the reason standardized charts are used.
Each chart was recorded under bright, medium and dark exposure ranging from 640, 320, 160, 80 to 40 footcandles, which was measured by a light meter. Even with the use of the manual settings of FiLMiC Pro it is uncertain how much the result is influenced by automated image quality enhancements as we only get to see the final rendered image.

During the camera test a shutter speed of 1/100 was locked in the app, but when the image go too dark the app would still reduce it 1/50 automatically. Which affected the shutter speeds relation to the drama rate. While the algorithms do help the consumer a lot, they can be a big hassle for professionals as they constantly have to check and eventually reset the settings.

The cameras limitations quickly became visible during the first recording. At it was done at 640 foot candle the sensor couldn't handle the brightness at a 1/100 shutter speed as the lowest possible ISO is 22.

8.1 Dynamic Range

The dynamic range is the amount between the lowest and the highest values that can be portrait by the camera. Higher dynamic range is always better as it means that more details and values can be seen. The higher the amplification level of the signal the lower the difference between the signal and so the dynamic range.

The ideal test for dynamic range would require a setup where a series of pure optical glass filters with a range of neutral densities mounted in a thick plastic plate is placed in front of a light box that produces diffuse, uniform illumination. This setup is superior to a printed chart as there is no texture or inconsistence from lighting the chart. (Jennings, “Noise and Dynamic Range Results Explained.”)

As this setup was not available the less accurate, but simple method of using a Accu-Chart HGSC Grey Scale chart was used.

> *“The 11-Step Grey Scale Chart is an extended range test chart intended for use with high-performance video cameras including both CCD and tube types. The chart consists of two arrays of 11 neutral grey patches or "chips" ranging in reflectance from 2% of approximately 90% (about 5.5 f-stops). The arrays are arranged so that one increases in reflectance from right to left and the other increases left to right. The strips are mounted on a uniform grey background with a reflectance of 16%. A black-white-black test object in the center of the chart provides a black (<0.5% reflectance) reference for adjusting dead black level in amplifier set-up as well as a "super-white" (90% reflectance) patch for setting peak video in many applications.”* (“Accu-Chart HGSG. 11 Step Grey Scale, Gamma Compensated - Filmtools.”)

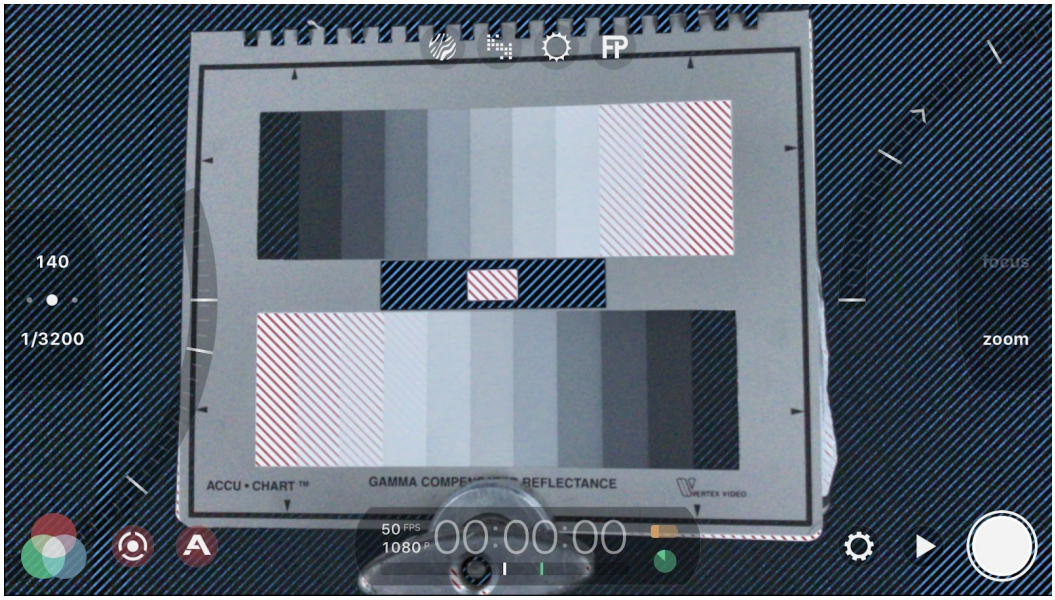


Figure 5. Peaking in bright and dark areas while using the zoom function.

Looking at the image above, even without a detailed analysis it is clear that the image starts blowing out on both ends of the luminance. But comparing it with a recording from close up the differences between the greysteps are still clearly visible. While the peaking option in FiLMiC Pro is a useful tool, this suggests that it is set to quite a high percentage. Unfortunately the chart only covers about 5.5 f-stops, which gives us not clear indication whether the iPhone would fulfill much higher required 14 f-stops for the broadcasting standard.

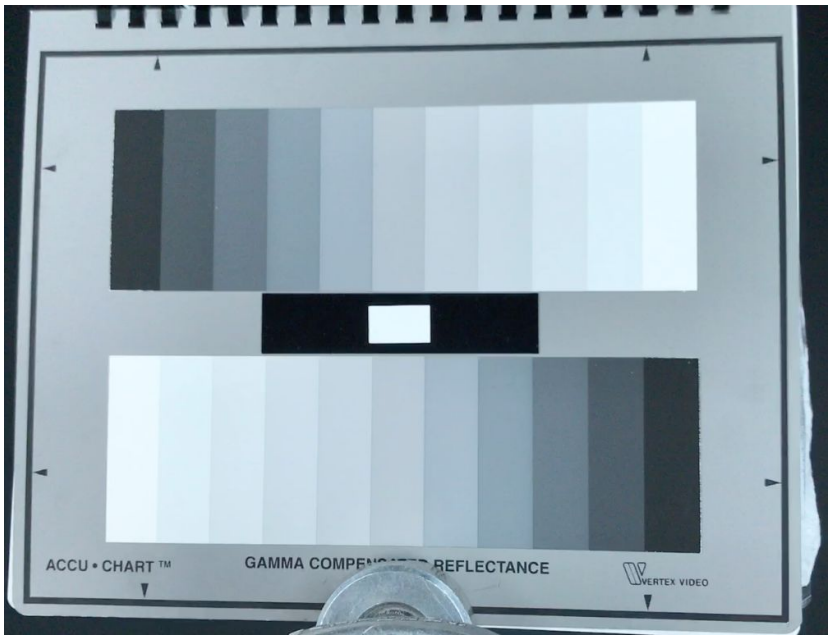


Figure 6. Step chart recorded at 160 foot-candle with 32 ISO

8.2 Color Accuracy

To test the accurate capturing of colors the best practise is to use a Colorchecker chart. A popular model is the x-rite Color Checker, which contains 24 different colors. Six of them are greyscales while the other colors try to imitate natural occurring colors like the blue sky, human skin and foliage. While many test charts do not represent real colors very well, this is a decent approach to get a feeling of how the camera will react to real scenes.

The results of the recording of the color checker chart are referenced back to the color data table with the average values of the colors provided by x-rite.

No.	R	G	B	R	G	B
1	171	112	92	115	82	68
2	245	182	164	194	150	130
3	109	165	202	98	122	157
4	117	143	83	87	108	67
5	165	159	214	133	128	177
6	107	232	215	103	189	170
7	250	145	75	214	126	44
8	69	105	204	80	91	166
9	250	87	104	193	90	99
10	110	60	108	94	60	108
11	183	222	93	157	188	64
12	250	188	80	224	163	46
13	42	65	176	56	61	150
14	75	184	99	70	148	73
15	227	61	64	175	54	60
16	250	211	81	231	199	31
17	240	84	170	187	86	149
18	0	167	204	8	133	161
19	237	235	232	243	243	243

20	209	209	209	200	200	200
21	185	189	189	160	160	160
22	142	143	141	122	122	122
23	94	97	94	85	85	85
24	43	37	30	52	52	52

The left three columns of the table show the results of the camera test, while the right ones are the reference numbers taken from the producer of the chart. Based on these numbers the CIE L*a*b numbers can be calculated and the comparison can be made in a colorspace graph.
The easiest and most effective way to analyse charts like the Colorchecker and step chart is by using analysing software like Imatest provides them. This software can automatically read out all the required data needed from an image and supports all standardized charts. However it is used for the professional field and does not come for less than 3,000$.

But just by looking at the RGB numbers alone big differences can be made out and it suggests that not all of it is due to the sensor, but is very likely rooted in the algorithms used to improve an image. As more saturated images look better to the viewer it seems like the iPhone oversaturates many colors on purpose. To figure out how this algorithm works a second test shooting in the FiLMiC Log option would have to be made.

Figure 7. Color chart recorded at 160 foot-candle with 39 ISO

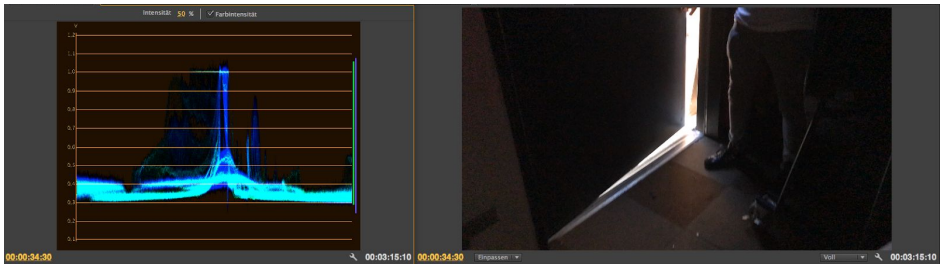
No.	Number	sRGB			CIE L*a*b*			Munsell Notation Hue Value / Chroma	
		R	G	B	L*	a*	b*		
1.	dark skin	115	82	68	37.986	13.555	14.059	3 YR	3.7 / 3.2
2.	light skin	194	150	130	65.711	18.13	17.81	2.2 YR	6.47 / 4.1
3.	blue sky	98	122	157	49.927	-4.88	-21.925	4.3 PB	4.95 / 5.5
4.	foliage	87	108	67	43.139	-13.095	21.905	6.7 GY	4.2 / 4.1
5.	blue flower	133	128	177	55.112	8.844	-25.399	9.7 PB	5.47 / 6.7
6.	bluish green	103	189	170	70.719	-33.397	-0.199	2.5 BG	7 / 6
7.	orange	214	126	44	62.661	36.067	57.096	5 YR	6 / 11
8.	purplish blue	80	91	166	40.02	10.41	-45.964	7.5 PB	4 / 10.7
9.	moderate red	193	90	99	51.124	48.239	16.248	2.5 R	5 / 10
10.	purple	94	60	108	30.325	22.976	-21.587	5 P	3 / 7
11.	yellow green	157	188	64	72.532	-23.709	57.255	5 GY	7.1 / 9.1
12.	orange yellow	224	163	46	71.941	19.363	67.857	10 YR	7 / 10.5
13.	blue	56	61	150	28.778	14.179	-50.297	7.5 PB	2.9 / 12.7
14.	green	70	148	73	55.261	-38.342	31.37	0.25 G	5.4 / 8.65
15.	red	175	54	60	42.101	53.378	28.19	5 R	4 / 12
16.	yellow	231	199	31	81.733	4.039	79.819	5 Y	8 / 11.1
17.	magenta	187	86	149	51.935	49.986	-14.574	2.5 RP	5 / 12
18.	cyan	8	133	161	51.038	-28.631	-28.638	5 B	5 / 8
19.	white (.05*)	243	243	242	96.539	-0.425	1.186	N	9.5 /
20.	neutral 8 (.23*)	200	200	200	81.257	-0.638	-0.335	N	8 /
21.	neutral 6.5 (.44*)	160	160	160	66.766	-0.734	-0.504	N	6.5 /
22.	neutral 5 (.70*)	122	122	121	50.867	-0.153	-0.27	N	5 /
23.	neutral 3.5 (.1.05*)	85	85	85	35.656	-0.421	-1.231	N	3.5 /
24.	black (1.50*)	52	52	52	20.461	-0.079	-0.973	N	2 /

Cie L*a*b* values use Illuminant D50 2 degree observer sRGB values for Illuminate D65.

Figure 8. Colorchecker reference chart

8.3 Automatic Setting

Even though it is often the point of critique from professionals, the automatic algorithms behind the iPhone camera are also what creates unique possibilities and a simple way to approach certain scenes. There are many things that can be simplified by using these functions, whether it be focus tracking, white balance or life exposure change. Of course it is always tricky to use videos like that in post production as the metadata constantly changes. One of the camera tests done during this research was to see how the automatic setting reacts to quick and harsh changes of available light. The following images show the transition from a dark room to an outside space on a lightly clouded day. They are shown in 30 second steps.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Farbintensität
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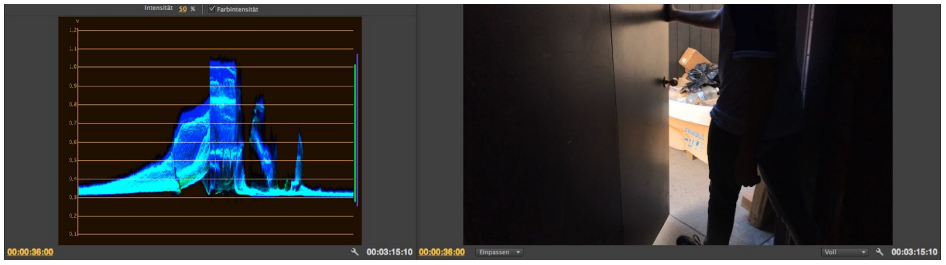
00:03:15:10
Einpassen
Voll


Intensität 50 %
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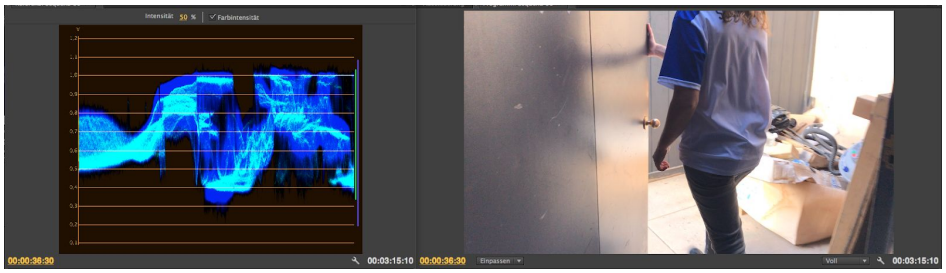
Voll


Intensität 50 %
Farbintensität
00:00:36:30
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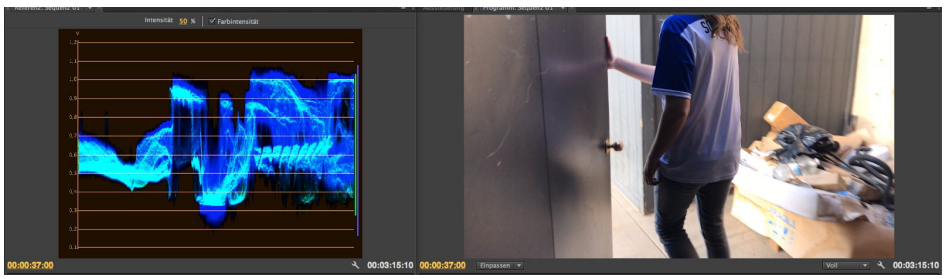
Einpassen
Voll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Farbintensität
00:00:37:00
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Einpassen
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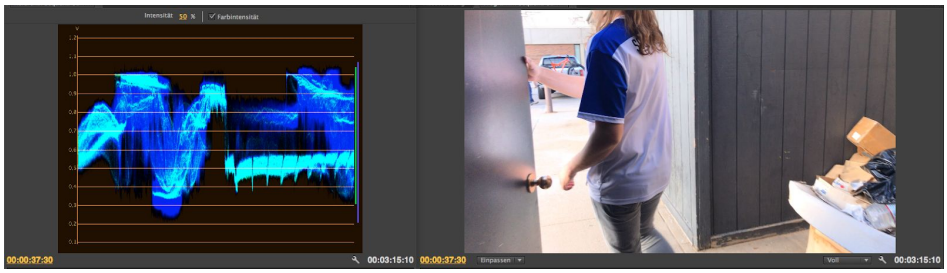
Intensität 50 %
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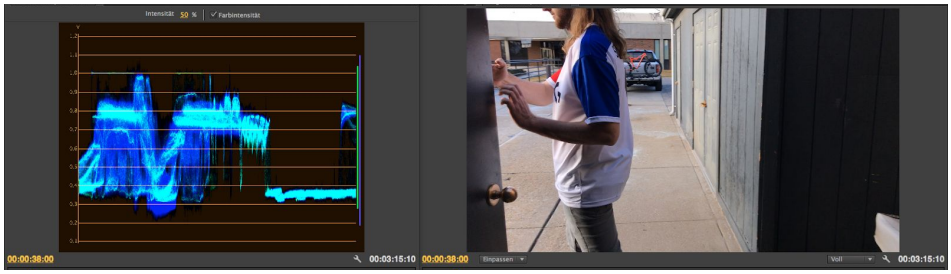
Intensität 50 %
Farbintensität
00:00:38:00
00:03:15:10
Einpassen
Voll

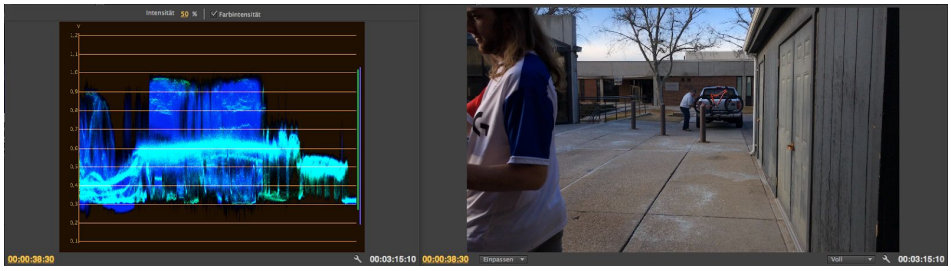

Figure 9. Waveform and video of live exposure adaption

9 Audio and Sound

As mentioned earlier this paper does not delve into the subject of audio recording with mobile devices, as the majority of productions that used mobile phones to record their video material did use professional audio equipment. While in camera recording is an option even in the professional area, it is extremely rare that the microphone and the camera are married in one machine. Parameters like distance to the audio source and the microphone size are vital to pick up fine details in regards to audio. There are already products like Lavalier microphones that are developed to work with a mobile device as a recorder and apps that support settings a Fieldmixer would have. However they do not achieve the quality and versatility traditional sound gear provides and are therefore still disregarded.

Many productions, who have worked with mobile devices have claimed that even when working on a Low-Budget and with iPhone cameras they strictly stick to professional audio equipment. The sound department on Tangerine used a SD 664 production mixer, boom mics, and lavaliers for the production. (Stella, “12 pro-Caliber Videos You Won’t Believe Were Shot on an iPhone.”)

10 Storage and Data Rate

Mobile devices are an important tool of our time and not only are they used in as tools for storytelling, but rather become part of many stories set in the current era. Movies and TV shows start integrating the devices into the story and let the characters use Snapchat, FaceTime and other apps that make use of the device’s camera. The easiest way to use these storytelling tools is by actually recording it with the device itself and screencapping what the device records. One of these shows is Disney Channel’s Andy Mack, where the characters communicate via FaceTime. As the show is produced for Broadcasting it only uses ProRes encoding. The Digital Imaging Technician of the show, Mindy Trim, points out that the quality of the recording is less of a problem than the data rate and formats the mobile devices are able to record with. Due to heavily compressed video a lot of data that would be available gets lost in the process. Another big issue during the production itself is the battery life of these devices that gets strained a lot

during recording. Especially the aspect of battery life is relevant for production and has already been pointed out by other professionals that decided to shoot their project on a mobile device. Even when the image quality is sufficient for Broadcasting there is little to gain, if it cannot be used practically on set therefore data rates, formats and battery life of current iPhone generations have been analysed.

Apple itself offers the heavily compressed formats H.265 and H.264.

FilmicPro Data Rates:

- Filmic Extreme
  Lets the user set a target range of 100mbps for 2k, 3k and 4K capture. When reducing the quality to 1080p the target is 50mbps.
- Filmic Quality
  Can record up to 1080p at 32mbps.
- Apple Standard
  The data rate that is used on the iPhone when recording with the regular camera app. (around 47mbps in UHD and 16mbps in HD)
- Economy
  A unspecified low bit rate recording is made. (filmicpro.com)

The video encoding format and the resolution determine how much storage a video approximately needs. There is no exact number one could follow all the time as the size varies on how complex the video is. In iOS 11, Apple added support for the High Efficiency Video Coding (HEVC, or h.265) format, which can make the same video up to 50% smaller than the standard h.264 format. While this is great for the storage using these compressed formats means a lot of image information is lost which cannot be restored for post-production and color grading.

The following chart shows the from Apple estimated amount of storage needed for different formats and resolutions.

	1 minute h.264	**1 hour h.264**	**1 minute HEVC**	**1 hour HEVC**
720p HD @ 30 frames/sec	60 MB	3.5 GB	40 MB	2.4 GB
1080p HD @ 30 frames/sec	130 MB	7.6 GB	60 MB	3.6 GB
1080p HD @ 60 frames/sec	200 MB	11.7 GB	90 MB	5.4 GB

1080p HD slo-mo @ 120 frames/sec	350 MB	21 GB	170 MB	10.2 GB
1080p HD slo-mo @ 240 frames/sec	480 MB	28.8 GB	480 MB	28.8 MB
4K HD @ 24 frames/sec	270 MB	16.2 GB	135 MB	8.2 GB
4K HD @ 30 frames/sec	350 MB	21 GB	170 MB	10.2 GB
4K HD @ 60 frames/sec	400 MB	24 GB	400 MB	24 GB

One of the iPhones big drawbacks is that there is no way no expand the storage. The iPhone 7 comes with storage options for 32GB, 128GB or 256GB. Shooting on the FiLMiC Pro App in maximal quality at 1080p/50fps needs around 600MB/minute which would come up to 36GB per hour. While 256GB seems a lot, it should be considered that the above chart shows the very compressed formats HVEC and h.264, and even the highest quality FiLMiC Pro offers does not take much more storage, which suggest how compressed it still is. The encoding formats Apple offers are far from raw footage, but if they improve anytime soon one can expect much higher data rates.

Storage is not the only struggle when working with big files, especially when recording in 4K fast writing drives are needed. While iPhones do not offer expandable storage that also means they completely avoid slow storage options like SD cards. Apple only uses SSDs, which are way faster than SDs. They use NAND chips and each chip has its own channel, therefore a SSD is faster the more chips it contains. Apple uses 16GB chips, which makes iPhones with more storage faster as they contain more chips to distribute the data to.
(Baram, “PCIe/NVMe in Mobile Devices.”)

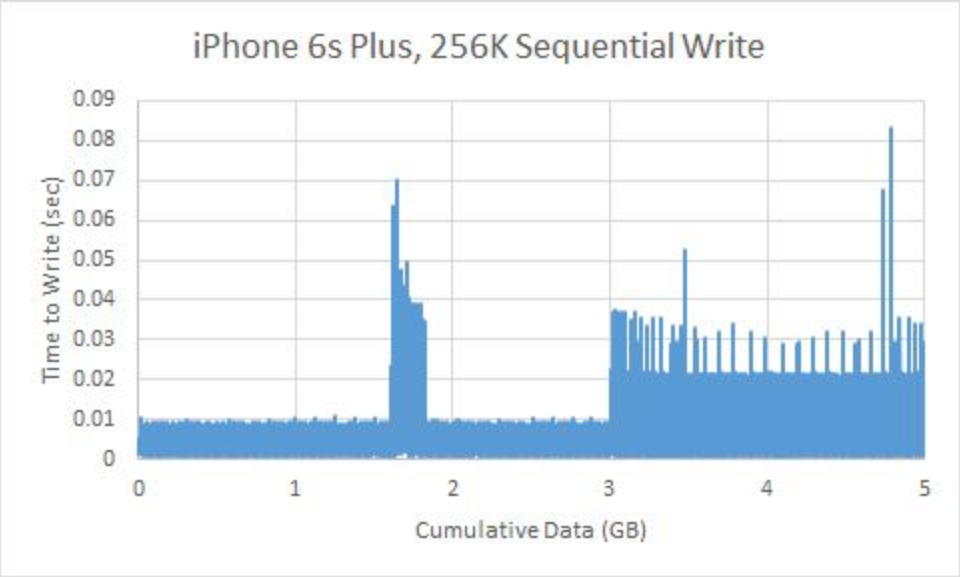

Figure 10. Sequential writing when recording video

This graph suggests that when recording for a long period of time the mobile device could have troubles keeping the quality up. Further research would be in order to determine how this behavior affects the final video and if there is a noticeable loss in image quality when the bandwidth slows down and the cache is overrun. It is a known problem when using DSLRs for video recording that the camera just shuts down after a certain time, when the video information is too much to process for either the processor or the memory card. As DSRLs are mainly conceptualized to use as photo cameras these issues might reflect on other devices as well.

11 Battery life

In a camera test, Arun Maini created for his youtube channel, he compares 5 smartphones and how their battery life holds up performing tasks that drain a lot of battery life. Running the camera was even one of the more straining tasks for the batteries. He set the brightness of the phones to the maximum, turns on the flashlight and runs various tasks on the phone for 10 minutes. One of them is the front camera. These are the battery percentages the phones lost:
iPhone7 - 25%
iPhone8 - 23%
iPhone8+ - 18%
Samsung Galaxy S8 Plus - 16%
Oneplus 5 - 14%

Which would allow for only about 40 minutes of filming on the iPhone7 and a little over 50 on the iPhone8+. Even without the flashlight running the time will be way too short to properly use it on set.

The only solution would be to constantly charge the phone which takes away it's flexibility or use multiple phones, which makes the data management more difficult and of course is more expensive and complicated as the switching and adapting the settings consumes a lot of time. Of course there are many factors that affect battery life like the age of the battery or the temperature of the environment, therefore these numbers can vary quite a lot. The test has been performed on fairly unused phones, but one should also consider that the flashlight used up some of the power. Still in can give a good scale on what the limits of mobile devices are.

The full test can be found here: https://www.youtube.com/watch?v=IbSjUq_kvSM

12 Conclusion and Outlook

While the main focus of this paper was to compare the image quality the mobile device cameras could archive with the standards used in broadcasting, the practical use of these cameras quickly made clear that there are other aspects to consider apart from the technical quality aspects. As the question was designed to answer whether it is feasible to use mobile devices during production as a camera, it became apparent that data rates, storage and battery life of the devices plays a huge part in how they could be used in practice and sets many limitations that still have to be overcome, which is why chapters about the battery life and data rates were added.

The research also made clear that in order to perform an accurate and relevant camera test regarding image quality many aspects have to be considered. Taking in account that even acclaimed research groups fail to meet all the resources.
The method for camera tests developed by the CPIQ is an extensive procedure and it is still in the process. With technology and mobile cameras constantly evolving creating a sustainable standard is almost impossible as it has to adapt constantly to the changes on the market.

During the work on this research paper two new iPhone models were introduced and many other phones, whose mobile camera exceeds the Apple products. While some aspects might be consistent for a few years many are already changing and creating a state of the art is a difficult undertaking. Measuring methods constantly have to adapt with the new algorithms and specifications. The development of a unified measuring standard will be a great improvement when utilized by the developers and will give the consumers a clearer image on the pro and cons of specific models instead of just being able to compare the final results.

While the iPhone 7 creates great images under the ideal circumstances and environment it still lacks in other areas and has trouble dealing with low-light situations and any use of the zoom function. Even though it works well for a quick point and shoot video due to image quality enhancing algorithms and good automatic adaptations, it is hard to control manually.
Apart from the visible deficits in image quality the iPhone 7 also does not achieve all specs demanded for the broadcasting standard. The question whether iPhones conform the HD

broadcasting standard can definitely be answered with a, from the purely technical and theoretical aspect, no but when taking in account the special creative and visual aspect they provide, from the practical viewpoint, yes. It is clear that that mobile phone cameras cannot simply replace a regular broadcasting camera, but given the right circumstances and reasons they can give productions more freedom in how to tell a story. When properly used, with enough available light, the right Add-Ons and handling their image quality can integrate itself into a show.

The amount of Apps and Gadgets developed for mobile cameras in the past years provides an exciting outlook on what will be possible in the future. Considering how easy it is to programm and manipulate the camera settings it could be possible that the automatic settings that are currently being avoided by professionals could soon be used to their advantage.

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List of Figures