Inhibition of mobile phone cameras

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Abstract

In this report different approaches to inhibit mobile phone cameras externally are discussed. The ultimate goal is to find an approach that can be integrated into a wearable. The Approaches covered in this report are: disrupting auto-focus, obscuring using pulsing a light source and blinding using a direct light source. In the end no good way of disrupting auto-focus was found, since it requires the scene to be made beyond recognizable. As for obscuring using pulsing light sources, this is not usable in practice. It only works well at small distances in poorly lit environments because the difference between on and off are clearest in these conditions. Blinding using a direct light source like a laser is possible and can even be achieved with low power lasers to prevent harm to people. It works in practically all indoor locations and also outdoors on overcast days. However, it is difficult to integrate due to the fact a laser would have to be constantly aimed at all surrounding lenses.

1 Introduction

1.1 Context

Cameras are all around us in this day and age and are a vital part of our daily lives. However, photos and videos can contain unknowing bystanders without their consent. So with the increasing number of cameras the amount of these incidents also increase. This issue becomes even more of a concern when looking at the speed information can spread on social media.

In order to provide some form of privacy for these people, this report looks into possible ways to prevent image capture that can be integrated into a wearable. For this wearable to function, a way to blind cameras or a way to obscure specific objects for cameras is vital. Earlier investigations have explored the blinding approach using non-visible light. However, this did not work on all cameras [1].

1.2 Research question and requirements

This report will cover multiple methods to attempt inhibiting cameras. These methods will be judged on the ability to remove someone's face from an image, on the effect it has on the people in its surroundings and whether there are any restrictions to the situations in which these methods function. This can be summarized in the following research questions:

How to prevent someone's face from being photographed without control of the camera?

How can this be achieved with minimal impact on a human eye?

Are there any scenarios in which the proposed solution does not work?

To be able to answer these questions some requirements have to be set up for the first two. First off, preventing a face from being photographed could either refer to it being partially or completely obscured. Simply ruining the picture can also result in it not being put on social media, but this is a bit less secure for the user. As for the impact on the human eye, this refers to the fact that the method used should not be too much of a hindrance and definitely not harmful to the people in its surroundings. With this in mind some requirements can be made. For preventing a face from being photographed the requirements are listed starting with the most preferable result and ending with an acceptable result, these will be the following:

- The face is completely obscured and cannot be recognized.
- The face is partially obscured but can sometimes be recognized.
- The face can be recognized but the picture is ruined.

For the impact on the human eye the requirements are ordered from most preferred to acceptable. These will be the requirements:

- The method used is not noticeable.
- The method used is not bothersome to surrounding people or the user.
- The method used is not harmful to the human eye.

1.3 Cameras in question

To increase the odds of finding a successful solution only the most common cameras will be considered in this report. In 2017, 85% of the digital pictures taken are made by mobile phones according to market research done by Statista [2]. Also, it is reasonable to assume that mobile phones will be even more relevant than other cameras since they have an internet connection giving them easy access to social media. This results in those pictures being spread much quicker making them a larger concern than pictures that aren't made with phones. For these reasons, the methods provided in this report will focus on inhibiting the cameras of mobile phones.

1.4 Covered methods

As stated in the abstract three methods will be covered in this report: Disrupting focus, obscuring with visible light and blinding with visible light. The first of these three is going to explore whether it is possible to bring surrounding cameras out of focus. There will be looked at the different auto-focus methods phones use and how they can be disrupted. The second, obscuring with visible light, will look into illuminating a face with short pulses. By using frequencies higher than the human eye can notice an attempt is made to distort photo's. Lastly, a laser will be used to shine on the camera lens. There will be looked at the required strength for this laser and whether the required strength is safe to use or not.

2 Disrupting focus

The first possibility that will be explored is to bring the camera out of focus to blur the image. To see whether it is possible to do so there will be looked at the most common methods of autofocus. After these have been identified and investigated, there will be looked at how they could be disrupted.

To start off, there are roughly two catagories of auto-focus: passive and active. Passive autofocus relies on just the data from the captured image itself or a preview of it. While active auto-focus methods rely on separate setups to determine the distance between the lens and the object of interest. Modern mobile phone cameras often use one of two passive auto-focussing methods: auto-focus by contrast or by phase [3]. Thus, these will be elaborated on.

-1		0	1		1	1	1
-1		0	1		0	0	0
-]	L	0	1		-1	-1	-1
Gx					Gy		

Figure 1: Figure showing the filter matrices for x and y [4]

2.1 Contrast auto-focus

Auto-focus based on contrast uses an algorithm to maximize the contrast of a specific area in the picture. There are many different algorithms which achieve this, an example of this would be the Prewitt Gradient Edge Detection algorithm. While it is often used as an edge detector, the thickness of the edges is also a measure for how sharp the image is. This algorithm uses two digital filters in order to detect horizontal and vertical gradients and edges. The filters can be found in figure 1. As can be seen, the filters are subdivided in a horizontal an vertical filter of which the outcomes are combined using equation 1. The algorithm will try to maximize this value in the area of interest. [4]

$$F(i,j) = \sum_{i=1}^{M} \sum_{j=1}^{N} \sqrt{Gx(i,j)^2 + Gy(i,j)}$$
(1)

Auto-focus based on contrast has no way of telling in which way it is out of focus. In other words, it cannot tell the difference between whether its current focus point is too close by or too far away. Also, while attempting to find the optimal focus point it overshoots that point multiple times. This results in the fact that auto focus based on contrast is quite slow and thus also performs poorly when trying to focus on a moving object. [3]

Another issue of contrast auto-focus is that if there is poor illumination, it will have troubles focussing. In these type of situations an assist lamp is used to illuminate the object of interest, which is often seen on phones. [5]

2.2 Phase auto-focus

The other auto-focus method used by mobile phones is by means of phase detection. In this method, the intensity pattern of incoming light from two small portions on opposite sides of the lens are compared. Two separate lenses are sometimes also used. Based on phase difference, the error in the lens position can be calculated and in one movement the focus will be corrected. This results in a fast focus compared to contrast auto-focus. Unlike contrast auto-focus it has no issues tracking a moving object while keeping it in focus. However, it does have the downside of not focussing as accurately as contrast auto-focus but this is hardly noticeable for the human eye [3]. These cameras also come with two type of focus points: normal and cross-type. The difference being that the normal focus point is only capable of lining up the intensity pattern in one dimension while the cross-type does it in two dimensions. In case of the normal one, this can hinder focus if the scene looks the same across the entire horizontal or vertical line. For cross-type the entire scene has to look the same[6] [7].

2.3 Disrupting phase and contrast auto-focus

Since phase auto-focus uses the same principle of operation as our eyes, it cannot be disrupted without disrupting our vision as well. This leaves only contrast auto-focus. While this method has issues with bringing moving objects into focus, it is very difficult exploit this property. When focussing on an object there is a certain range of distances that all are in focus. This range is called the depth of field and is defined as the distance between the closest and the farthest objects in focus [8]. When the motion falls within this range a camera might still try to find a better focus. However, due to the fact it is already close to the required focus it will only make small adjustments resulting in the object staying in focus the entire time. This can be avoided by covering a large distance in a small amount of time, but this too has limits. The movement has to fast enough to get out of the depth of field before the camera can refocus. The fact of the matter is that this range is not static, it is dependent on how close an object is and on the camera. This is due to the fact that it is dependent on the angle at which light falls on the eye. For close objects the angle differs much more than objects that are far away. Also, the camera itself plays a big role. The manufacturer can choose an aperture such that the depth of field becomes much larger than that of the human eve. An approximation of the depth of field can be found in equation 2 [8], here it can be seen that especially the distance to the object of interest has a large influence on the depth of field. So even if a technique could be designed to make these cameras adjust their focus, it will likely be limited to short range and it will not work equally well on all cameras making it inconsistent.

$$[H]DoF \approx \frac{2u^2 Nc}{f^2} \tag{2}$$

Where u is the distance to the object in meters, N the unitless f-number (depends on aperture and focal length), f the focal length in meters and c the circle of confusion in meters.

3 Obscuring using pulsing light sources

The next possibility that will be investigated is blinding or obscuring with visible light. Since one of the requirements is for the blinding method to have minimal impact on the eye, there will be looked at how the eye registers light compared to a camera. This will be used to see whether the differences can be used to prevent a face from being photographed with minimal impact on the eye.

3.1 CMOS camera

There are two types of image sensors: CCD and CMOS. Nowadays CMOS cameras have almost completely taken over [9]. For this reason CCD's will not be discussed.

The pixel of a CMOS camera consists of a photodiode, a potential well, an amplifier and a reset/readout mechanism. This can be seen in figure 2. When a photon strikes the photodiode an electron is generated and stored in the potential well. The potential well is connected to a source follower which acts as a buffer. When the pixel has been read out, the well will be emptied and the pixel is ready to start counting photons again. With this the camera can detect brightness but no color yet. For this a Bayer filter is used which can be seen in figure 3. This filter is a grid that consists of red, green and blue light filters and makes each pixel responsible for one

Anatomy of the Active Pixel Sensor Photodiode



Figure 2: Figure showing a single pixel of a CMOS camera and its components [10]



Figure 3: Figure showing a Bayer filter [11].

color. The reason there are more green filters is to make the color sensitivity of the camera more closely resemble the sensitivity of the human eye, which will be discussed later. The sensitivity can of course also be corrected for with amplification and this is actually still used to do the last fine tuning [10]. However, by using the Bayer filter this way, less amplification is needed and thus less noise is being amplified as well. Another function of the amplifiers are to account for different lighting conditions. Since mobile phones do not have a physical shutter, the pixels are constantly exposed. So to account for the lack/abundance of light the amplification is changed. Lastly there is the microlens, this is used to capture light that would otherwise be lost because it would fall on the circuitry.

3.2 The human eye

The human eye registers light using cones and rods. These rods and cones are grouped together in areas called summation areas. This area counts photons in a time window and sends a signal to the brain based on the amount of photons. This time window depends on the amount of ambient light and typically ranges from about 10 to 100 ms [12]. Each one of these summation areas has its own small nerve that connects to the brain meaning that information from all areas



Figure 4: Figure showing the sensitivity of the human eye, CCD and CMOS cameras to different wavelengths.

can be accessed simultaneously by the brain.

Just like the CMOS camera the eye has separate sensing elements for different colors, There are a couple of different rods and cones and they all have different wavelength sensitivities. When combining the spectral sensitivity with the density of the elements the total sensitivity is obtained, this can be found in figure 4. Since there is a lot of overlap in sensitivity in the yellow-green spectrum, the eye is also much more sensible to this color.

As for how different light levels are handled, this is done mostly through the iris. The iris regulates the aperture of the eye which also influences the amount of light that can enter. Additionally to this it is also possible to squint making even less light go through.

3.3 Summary of differences and similarities

So human eyes and cameras turn out to have a lot in common, they both count photons, they both have different sensing elements for different colors and they both are able to adjust for different brightness. The first difference lies in how this information is communicated to the brain or phone and the rate at which it happens. The human eye is able to send its information simultaneously about 80 times per second while a cameras does it pixel by pixel [13]. Since a camera can easily record 30 frames per second the frequency at which pixels are read out is much higher than the roughly 80 times per second of the eye. This also means that it can pick up on higher frequencies that the human eye cannot notice. By using these higher frequencies some pixel can be over exposed when being read out making them brighter than others. An experiment was conducted to see whether this could obscure a part of a picture by illuminating an object using this phenomenon. When this would be integrated into a wearable the object would be a face. The reason for illuminating the face instead of shining directly towards the camera is because this will likely have less impact on the surroundings. As long as it can make certain details hard to see it may be usable to make a face hard to recognize and otherwise it might still ruin a photo. The experiment on this effect is found in section 5.1.

Lastly, cameras are able to image scenes with bright light sources unlike eyes. If the light source is not too bright a camera can even make a picture of the source itself. An example of this can be found in figure 5 where the camera is adjusting the amplification to get as much detail as possible from the part that is being focussed on. A person would not be able to see the same amount of detail since allowing overexposure on a different part of the eye can lead to permanent



Figure 5: Figure mimicking different shutter times with different amplification, they were achieved by focussing on the notebook (left), in between the notebook and the lamp (middle) and at the lamp (right)

damage, cameras do not have that drawback. So, a camera is hard to blind if the point of focus is close to the light source. However, if that is not the case, it does not care about the brightness of surrounding light sources meaning that blinding will actually be easier. Since the wearable is meant for bystanders it can be assumed they are not the object in focus. This actually makes it easier to blind a camera.

4 Blinding using a direct light source

4.1 Overexposure and bloom

As was mentioned in the previous section, cameras are able to ignore portions of a picture leaving them overexposed. As seen in figure 5, the effect of overexposure can extend further than the light source. This is due to a phenomenon called bloom. When a pixel is overexposed it will have too many charges. When new charges are added there will be no space on the current pixel and they can end up at a neighbouring pixel. These neighbouring pixels can also get flooded with charges causing their neighbours to receive extra charges as well.

4.2 Most suitable color

Due to the fact the charges are created before amplification it is also important to know what the sensitivity of silicon is to different wavelengths. Looking at figure 4 it can be seen that CMOS sensors are especially sensitive to green till red light. This means that laser with a wavelength between 500 and 700 nm are the best to use to cause bloom, which of the two is better depends on the camera itself. It is possible to achieve the same sensitivity through amplification in which case red would be more preferable since it is less noticeable to the eye. If the sensitivity is achieved by the microlens or light filter, yellow would be more preferable since this would cause more bloom in this case. To see how much light exactly is needed to blind a camera an experiment was conducted. This experiment can be found in section 5.2

5 Experiments

To check how effective certain effects are at preventing image/video captures in practice, some experiments were conducted. The first experiment is about using pulses of higher frequency mentioned in section 3.3. The second is about the amount of light needed to obscure an object with blooming effects and the effect of different environmental lighting mentioned in section 4.1.

5.1 Experiment 1

The goal of this experiment is to investigate whether the effect mentioned in section 3.3 can be used to obscure a face. There will be looked at the influence of frequency, duty cycle and the use of alternating red, green and blue light. The frequencies are chosen such that no or little flickering can be noticed by humans. This experiment was split in two sets: one with the white led and one with the RGBW led. During the first set this effect was noticed and investigated on the spot. Thus, during the second set, the effect was known and the setup was changed to make this effect more apparent. The changes are: Less environmental light, this makes the difference between on and off larger and smaller distance to the illuminated surface, this makes the intensity of the light higher.

Following here are the materials used during the experiment:

- 3W white power led (set 1) [14]
- RGBW power led (set 2) [15]
- Arduino Uno [16]
- Nokia 6 (capture device) [17]
- Mosfets [18]

The setup for the first set used the Arduino Uno as wave generator which drives the mosfet. Two measurements from this set have been put in this report: figure 8 using 125 Hz and a duty cycle of 90% and figure 9 using 125 Hz and a 50% duty cycle. The leds were supplied with power such that if the duty cycle was 100%, it would meet the rated wattage in the datasheet.

The setup for the second set can be seen in figure 6. It uses the Arduino as a wave generator which drives the mosfets and the 5V pin is the power supply. A 100 Ohm resistor was added in series to prevent loading the Arduino too much and to protect the leds. The difference in environmental light is made using the flashlight of the phone. The different frequencies used can be found in the captions of the figures in the results.

5.2 Experiment 2

The goal of this experiment is to investigate the required laser power to cause enough bloom to obscure a face or a part of it. Also the effect of different environmental light will be investigated. The reason for using a laser is that it provides a direct light beam which is not visible for people in its surroundings but only at the camera lens. So if this can be implemented it will be the only method proposed in this report to meet the requirement of not being noticeable.

To mimic a lower power laser, the laser was de-focussed such that it lit an area of about 10 cm^2 instead of just the lens. To get an idea of how much less power this actually is, the ratio between the area of the de-focussed laser the lens will be compared. This is roughly 140. The intensity of the new dot is still slightly higher in the center so this number will likely be a bit lower in reality. Taking this into account an estimate of a factor 100 should not be too far off. So the pictures taken with lower the de-focussed laser should be around 10 μ W which should be a class 1 and is thus not harmful in any way. In case the laser is focussed with its 1 mW power it is considered a class 2 laser and is thus harmful for exposure times above 0.25 seconds [19].

The setup can be seen in figure 7. The laser is being supplied with 3V and the current draw fell below the set limit of 40 mA. The distance between the laser and the camera was approximately 80 cm. The lamp was used to cause different environmental lighting but any methods which achieves this can be used.

Following here are the materials used during the experiment:

- 1 mW red laser [20]
- Lux meter [21]
- Nokia 6 (capture device) [17]
- Lamp



Figure 6: A picture of the setup used in experiment 1, the phone will be placed on the books and the led is mounted on the black heatsink.



Figure 7: A picture of the setup used in experiment 2, the phone is placed on the left where the metal boxes are. The laser is aimed at the lens of the camera and is stuck in the vice in front of one of the faces

6 Results

6.1 Experiment 1



Figure 8: Set 1: Two consecutive frames with a frequency of 125 Hz and a duty cycle of 90% of the 3W led.



Figure 9: Set 1: 125 Hz and a 50 % duty cycle using the 3W led. On video the lines can be tracked, but as can be seen they are not visible on one single frame.





Figure 10: Set 2: A picture of the effect using the RGB led at 62.5 Hz, left is with little environmental light and right is with a lot of environmental light.





Figure 11: Set 2:A picture of the effect using the RGB led at 125 Hz, left is with little environmental light and right is with a lot of environmental light.



Figure 12: Set 2:A picture of the effect using the white led (of the RGBW) at 62.5 Hz, left is with little environmental light and right is with a lot of environmental light.



Figure 13: Set 2:A picture of the effect using the white led (of the RGBW) at 125 Hz, left is with little environmental light and right is with a lot of environmental light.

6.2 Experiment 2

Note that in all pictures the face on the left is the object in focus.





Figure 14: A picture of a foam face with a 1 mW laser shining on the lens. On the left the face is illuminated by 350 lux and on the right with 850 lux.



Figure 15: A picture of a foam face with a de-focussed 1 mW laser shining on the lens. On the left the face is illuminated by 300 lux and on the right with 2600 lux.





Figure 16: A picture of two foam faces with a de-focussed 1 mW laser shining on the lens. On the left the faces are illuminated by 500 lux and on the right with 1280 lux. The left face is the being focussed on by the camera.



Figure 17: The same setup as in figure 14, however, now the laser is object in focus.

7 Discussion of results

7.1 Experiment 1

As can be seen when looking at figure 10 and 11, multiplying the frequency by 2 increases the number of stripes by 2 as well. The increase in the amount of lines appears to make the effect less noticeable overall. As the frequency drops below 60 Hz, flickering becomes more apparent.

So a frequency of 60 Hz or slightly above is recommended. Also, the colors seem slightly different in these two figures. It seems as if two frames got taken into account because the colors are pink (blue and red), yellow (red and green) and light blue (green and blue). As to why this happened it might be that the phone picked up on the frequency which is rather close to 50 and 60 Hz of the grid. This means that these frequencies are probably commonly found in pictures and this might be the result of an algorithm that is made to counter flickering light sources at these frequencies.

Something which can also be noticed is that the transition of all results from experiment 1 are not instant. It has a small part where it transitions from one color to the other or dark to light. This could be one of the reasons why higher frequencies appear slightly less noticeable, as dark and light regions consist mostly of transitions. This is because the led does not go from 0 to 100% and back in an instant, the circuitry has delay. The exact cause cannot be definitively pinpointed as the led turn on/off times were not listed in their datasheets. Though they are likely so fast that it would not be noticed if faster ones were used, it is still important to use as fast as possible circuitry when trying to reproduce this effect. This is because the faster the transition is from on to off, the less blurred out the parts in between will be.

When comparing the situation in figure 9 and 13 there is a large difference in how noticeable the effect is. This could be because of 3 factors: the high amount of environmental light in figure 9, the light diffuser in front of the led in figure 9 and/or the distance to the object. By having more environmental light, the effect becomes much less apparant. This is due to the fact that the changes in lighting become less significant if there is another light source. At larger distances it also becomes harder to see. This is because the strength of the light from the led falls off and becomes even less significant compared to the environmental light. Another reason why this effect becomes weaker at a distanceLastly, there is the diffuser, this causes the light to be spread out a bit more and might also have played a role in weakening the effect.

Changing the duty cycle can be useful but it does come with some drawbacks. So first off, there is no real reason to use a higher duty cycle than 50%. This causes the light to become more apparent for people in its surroundings and only makes the effects smaller. Going lower than 50% can be beneficial since a higher intensity can be used while still remaining at the same intensity for people in its surroundings. Just like going higher than 50%, this also comes at the cost of the lines becoming smaller. This reduces the area of the image that can be distorted.

7.2 Experiment 2

Looking at figure 14 the face in the left picture can barely be noticed and in the right picture it is a little better but still hard to see. Any objects directly behind the laser are completely unrecognizable. This already shows that a 1 mW laser is more than enough to blind a camera. Figure 17 shows that the charge wells themselves are completely saturated since the pixels are still saturated even with the gain at its lowest. Now, the bloom effect in figure 16 appears quite a bit weaker than in figure 15 despite being at the same distance from the laser. This means that, unlike in figure 14, the potential wells are not saturated and the bloom can actually be still reduced using a lower gain on the amplifiers, which can be forced with more environmental light. This also shows that the wearable would perform worse the closer it gets to the object in focus. Lastly, the amount of lux does not seem to heavily influence the amount of blinding. In figure 15 the difference seems the largest and even there the de-focussed laser seems powerful enough to obscure a face. Because of this it is fair to say the method at least works for environmental lighting of 2600 lux. This means it will work in all indoor locations, outside too on overcast days and maybe even on non-overcast days when not in direct sunlight [22]. As mentioned in section 5.2, the de-focussed laser is not harmful to the human eye while the focussed laser is. The fact of the matter is that the focussed laser was able to blind much more effectively than the de-focussed one. A setup that could mimic the focussed laser with lower powered lasers is on that has multiple lasers at different points aimed at the lens. This causes the overexposure to be at different parts of the image and thus it can still cover the same area. However, since there is no longer one concentrated light beam, it is much safer for people in case they look into it.

8 conclusion

In summary, this report discusses the several ways that might be used to inhibit cameras. The goal was to try and find a method that could be integrated into a wearable. In the end no suitable method that is easily integrated into a wearable was found. At the start some requirements where made for specific research questions to determine how successful a method was. Now, the only thing that's left is to answer those questions and see what requirements each of the solutions met if applicable:

• How to prevent someone's face from being photographed without control of the camera?

To this question, the answer will be blinding cameras using a direct light source as this is able to meet the requirement of completely obscuring a face making it unrecognizable. No way of preventing capture by disrupting focus was found so that was unsuccessful. As for illuminating using a pulsing light source, the face will still be recognizable but it does have an impact on the image which could potentially ruin it.

• How can this be achieved with minimal impact on a human eye?

For the blinding using a direct light source the answers to this question would be to use a laser. A laser can isolate small spots like a lens and only illuminate that. This makes it unnoticeable for people in its surroundings but does introduce the potential danger of shining on someone's eye. Though, at an approximate power rating of 10 μ W it is far from harmful. The method of illuminating with pulsed light proposed in this report will be very noticeable for people in its surroundings. The first important note is that 60 Hz is the minimum frequency that should be used. There is already some flickering but it gets much stronger as the frequencies decreases making it bothersome for people in its surroundings. It can be made less impactful on the eye by lowering the duty cycle, this results in a lower perceived brightness for the eye. This does however increase the chance of the effect not being present on a frame. Lastly, alternating between red, green and blue light is more noticeable than on-off keying with white light for cameras but is no different for the eye.

• Are there any scenarios in which the proposed solution does not work?

Blinding using direct light is theoretically able to work in all scenarios. However, since safety is a concern, realistically it will not work outside on sunny days because this will likely require more

power. Also, it can be made such that it does not work in the next brightest lit environments in case the power should be lowered even further due to safety concerns. Finally, illuminating using pulsing light is less effective at larger distances due to the fact it takes up a smaller portion of the image decreasing the area at which the effect is present. Also, in environments of about 200 lux it is already barely noticeable ruling out almost every scenario during the day.

In the end, the advice is that if work is continued on the wearable to build upon the blinding using a laser. The first thing that would have to be checked is how strong the blooming is on different commonly used phones to check whether it will work on other phones as well. Like mentioned in section 4.2 the best color to use might depend on the camera.

If blinding performance is satisfactory, a way to reliably detect cameras is needed. Earlier investigations have been able to this using neural networks [23] or IR hot-mirror reflections from the lens [24]. When a reliable way is found a method of aiming a laser at the lenses has to be found. In case it proves to be too difficult a possibility would be to purposefully de-focus the laser making it project its light on a small circle instead of a single point much like done in this report.

It is also advised to not persue the other two methods any further. An exception would be if some new way of auto-focussing was introduced. In that case that specific method might be worth looking into.

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