The Historical Revolution and Progress of Camera Auto Focus Systems

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Abstract. The auto-focus system is an important part of modern cameras, not only single lens reflex (SLR) cameras but also mirrorless cameras. The reliability level of an auto-focus system usually determines the availability of a camera in the photography industry. Today the photography industry makes more strict requests for auto-focus ability, which means that the camera can work in more complex and difficult environments, such as the Olympics and ecological photography. The paper reviewing past related research and patents points out basic development rules of auto-focus system and prospect futural trends of it. This research found that the auto-focus technology experiences a process from active focus to passive focus, from contrast focusing to phase focusing and mixing focus, from separated focus module to phase detection auto-focus (PDAF). This research points out that several companies and scientists have had hard effects on it. In the future, auto-focus technology will become more reliable and intelligent with artificial intelligence and eye-control focus.

Keywords: Auto-focus, Contrast detection autofocus, Phase detection autofocus.

1. Introduction

The history of autofocus can date back to the 1960s. Canon showed an auto-focus camera subject at the Photokina expo in western Germany, but it was a mature technology because of its huge volume and complex system. In April of 1971, Nikon company achieved auto-focus technology with lens AF Nikkor 80mm F4.5. It used light-sensitive components to identify the position in which pictures in the focus frame become most clear. Importantly, the auto-focus technology is contrasting detection autofocus (CDAF). In November of 1977, the Konishiroku camera company released the first mass-produced auto-focus camera in history C35 AF. It used a visitronic autofocus (VAF) system by the Honeywell company [1]. The basic principle of VAF technology is binocular parallax theory.

Because it uses the light ray reflected by the target to achieve auto-focus, it can be considered as a kind of passive focus.

Besides passive focus, there is another way called active focus. In 1978, the Polaroid company released a camera that used ultrasonic focus. It is SX70 Sonar Autofocus. The SX-70 accords with all definitions of an SLR camera, so there is a viewpoint that considers it the first auto-focus SLR camera in history. By using ultrasonic echo to measure distance, it can achieve auto-focus in completely dark areas, which is an advantage of all active focus technology, However, it cannot work when it tries to focus on objects behind the glasses. What’s more, objects can absorb sonic waves will also influence them negatively.

In 1979, Canon published its first commercialized auto-focus camera AF 35M. It has an infrared LED and triangular measure system, so that it can focus in dark areas. As a camera that has passive focus and active focus together, the AF 35M succeeded in the photography industry. At this point, the auto-focus technology was still used by the affordable cameras besides the professional cameras [1].

In May of 1981, Canon company published an auto-focus lens NEW FD 35-70/4 AF, which adopted a way of using the lens to detect and focus. It integrates the ranger-finding device, motor, and batteries in a lens, which can make a camera with the same amount to achieve auto-focus. Later, the Ricoh company also adopted the scheme that using lenses to solve all the auto-focus work and published Ricoh AF Rikenon 50mm f/2 lens. However, the lens detection scheme means that each lens needs to install a focusing detection system. Using camera fuselage to execute the focusing detection work is more reliable [1].

In 1989, Pentax company published the auto-focus SLR camera ME-F and matched lens SMC 35-70/2.8 AF. Importantly, ME-F is the first camera with TTL technology in history. The meaning of TTL is that camera fuselage through the lens to execute contrast detection and using the lens to drive focusing. The historical scheme is very approached to auto-focus solution of the time. Especially, the contrast detection auto-focus can achieve focusing direction promptness. The Pentax company arranged two contrast detection sensors in the bottom of camera and make the theoretical focal plane fall into the middle of two contrast detection sensors. Then the camera can determine direction of focusing by detecting contrast radio of two sensors. This detection way is very near to the phase detection auto-focus [1].

In the Photokina expo pf 1982, auto-focus technology was the theme. Historically, the Olympus company published the OM-30 camera and matched the Zuiko auto zoom 35-70/4 auto-focus lens. The way OM-30 achieved focus detection is by translating the target scan into a video signal and detecting deviation of the video signal. OM-30 is the first commercial phase detection auto-focus camera in history. In 1983. Nikon company published the F3 AF camera, which used the TTL PDAF. Differently, Nikon company placed the focus sensor and batteries into DX-1 viewfinder. The camera through contact point to supply electricity to the lens motor. At the same time. Nikon company published AI AF Nikkor 80mm f/2.8S and AI AF Nikkor 200mm f/3.5S ED IF two auto-focus lenses with a focusing motor [1].

In 1985, Minota company shocked the photography industry, it published a7000 camera with brand-new a-amount. Minota a7000 is the first accepted practical integrated auto-focus SLR camera. Integrated auto-focus means using TTL PDAF and focusing through the lens motor or body’s motor, which continues until today. And its auto-focus ability has surpassed most professional photographers. The a7000 is a milestone of auto-focus history. After a year, Nikon company published F501 to be a competitor of a7000 [1].

However, Canon company’s competitor T80 camera suffered a big defeat.

The above is the most important part of auto-focusing development. The article will discuss a few examples of auto-focus technology in the early stage at first. And then the article will analysis some major PDAF ways. Finally, this article mentions some advanced auto-focus technologies that will be application in the future [1].

2. Process of Two Main Auto-focus Technologies

2.1. The Contrast Detection Auto-focus (CDAF)

Contrast detection auto-focus is still a popular focus technology today in conventional photography systems. It achieves auto-focus by detecting the contrast of camera sensors. Although the auto-focus speed of CDAF is slower than the PDAF, it is reliable and high-accuracy in static photos shooting.

The principle of contrast detection auto-focus is not complex. Its basic process is the analysis and calculation of the highest contrast ratio, Higher the contrast ratio, clearer the picture. During the process camera finding the correct focal point by moving the lens focusing part, the contrast ratio between adjacent pixels on the sensor will be higher. So, when the camera finds the contrast ratio of the picture is the highest, the focal point is correct [1].

In the range of focus adjustment, each adjustment position will correspond to a contrast ratio. These ratio data can form a function curve, which is called the contrast curve. Importantly, the contrast curve is a unimodal curve. The crest value of the curve implies the correct auto-focusing position. However, the camera processor doesn’t know the crest value, so the camera will drive the lens the motor in a direction at first. If the picture is becoming clearer, the camera can judge it as the auto-focusing direction. In this direction, the contrast ratio will become higher and higher until the crest value. When the camera detects the contrast ratio drops, it will turn back to confirm the crest value in a smaller field. This mechanical process will continue several times until the camera finds the correct focal point successfully [1].

Because the principle of CDAF is mechanical and simple, it has its advantages and disadvantages.

CDAF uses the CMOS and image professor to achieve auto-focus, so its cost is cheaper than other technologies. What's more, it has high accuracy in static photography. Because of its algorithm, a camera with CDAF doesn't need a high-performance professor.

On the other hand, the disadvantages of CDAF are obviously numerous in the photography industry. First, the speed of CDAF is limited to auto-focus algorithm and professor performance. Its principle causes the auto-focus process will experience repeated lens movement. Second, CDAF misbehaves when it faces moving objects at high speed, which limits its application in sports photography and ecological photography. In summary, although CDAF is a mature technology, it cannot complete some tasks by itself [2].

2.2. The Phase Detection Auto-focus (PDAF)

As the most popular auto-focus technology at present, phase detection auto-focus plays an important role in advanced cameras and camcorders. The three biggest camera companies, Canon. Sony and Nikon have developed the most technological PDAF in different ways in recent years. Upscale PDAF cameras are extensively used on significant occasions and scientific investigations.

The principle of PDAF is confirming the correct focal points by analysis the deviation of two direction phases. However, it is such a complex process, which involves different sensors technology, and algorithms. Producing the phase difference needs two phases to detect pixels on the left and right, like how humans' eyes work [3]. There are two mainstream technological ways. One covers half of the PD pixel (half-shield) used by Sony sensors and the other two pixels that use microlens together (Dual-PD) used by Canon sensors. Each one has its advantages and disadvantages, but they are all effective ways to detect different phases. The left shield pixel and right shield pixel have their own energy value because of the different light rays.

The second step is depicting different energy value function curves of right and left shield pixels. Each curve has its crest value, which can be used to calculate the phase difference by computing the D-value between it. With certain phase differences and distance between the left pixel and the right pixel, the camera can confirm the direction and movement amount of the lens [3].

Half-shield phase detection pixel is a common scheme on the sensor from Sony company. Half of the phase detection pixel is shielded to receive half of the signal. To obtain the complete signal of phase difference, it needs another PD pixel to shield another half of it. The more shield pixels, the faster the auto-focus, but will lose more useful signals. So, the manufacturers usually control the density of PD pixels by 1 percent to 3 percent.

Dual Pixel is used on Canon company's sensor. It separated the photosensitive a pixel into two parts, which are the left part and the right part. So dual pixel technology can achieve phase difference in a single pixel [4]. Because dual pixels can cover the whole sensor in the way, its auto-focus speed is the fastest. However, separating a single pixel into two parts caused serious attenuation of dynamic range.

Half-shield and dual pixel are mainstream technology of PDAF. On-sensor phase detection auto-focus. As advanced PDAF schemes, their common ground is combining phase detection with camera CMOS, which has been designed for advanced mirrorless cameras in recent years. The way the DLR camera achieves PDAF is more complex in the mechanical structure. The light reflector is translucent. One part of the light will be reflected to the viewfinder, and the other part of the light will pass through it and arrive with a single focusing module. The PDAF module of the DLR camera is a charge-coupled device (CCD), In order to generate phase difference on the CCD sensor, there is a separation lens in front of it. Different directions of light rays will cause different electrical signals on it. By analysis the phase of electrical signals, camera professor can achieve auto-focus. However, the single auto-focus module has unavoidable deficiencies. Theoretically, the optical path to the auto-focus module is the same as the CMOS of the camera. However, the DLR camera has an error value, which means that two optical paths cannot stay the same. There is a tiny difference between them. In most cases, it can be ignored, but sometimes the picture on the viewfinder will not be clear on the CMOS. By designing PD pixels on the CMOS, the problem is solved forevermore, which proves that mirrorless camera has more reliable auto-focus technology.

The advantages of PDAF are evident. Most importantly, PDAF can focus correctly in a short period. In contrast to the CDAF, the PDAF can adjust to a focal point at a time accurately without repetitive finding and calculating. So, it plays an important role in sports photography and wildlife photography which need a camera to lock in the target quickly. Secondly, PDAF is significant in the video shooting field. It is reliable in fast-moving scenes and fiercechasing. Third, the PDAF has excellent continuous focusing ability because of its real-time feedback way and high refresh rate. Fourth, PDAF has better performance than CDAF in the low light environment. The reason is the low light environment will reduce the contrast ratio of the target, which cause that CDAF cannot work normally. Finally, the PDAF consumes less energy than the CDAF with more efficient auto-focusing.

But PDAF is not perfect technology, it still makes mistakes sometimes. The cost of PDAF is higher than other ways. Because PDAF needs a more precise CMOS sensor with PD pixels and high-performance professor to renovate a large amount of data. What's more, PDAF sometimes fails to find the correct focal point with pure color objects and backlight environments.

2.3. The Depth from Defocus (DFD) Auto-focus

Traditional CDAF technology has proved that its biggest problem is low auto-focus speed. Although the operation of CDAF is not much today, Panasonic company has proposed a novel CDAF scheme in recent years. It is called DFD (Depth From Defocus) auto-focus.

Depth from defocus is a way to achieve auto-focus by mathematical modeling. At first, the technology needs to collect a large amount of defocus pictures and analyze the connection between definition, defocus degree, and other picture parameters. After massive calculations, the computer can set up models. The camera can use vague imaging to derive an offset between the correct focal plane and drive the lens to achieve auto-focus [5].

In contrast to traditional CDAF technology, DFD can obviously reduce the focusing time by only gathering two or three images. But DFD technology proposes high requirements to imagine professors because of the huge amount of calculation What's more, different lens have their own mathematical models, which means a camera needs to store several data. However, Panasonic company's camera only storage models of its own lens. So, the DFD is also limited to the type of lens.

2.4. PDAF, Eye-contact Auto Focus and Artificial Intelligence

Although PDAF technology has high speed and precision, the focus target is still decided by the camera sometimes. Camera's focus target will probably be different from the photographer's target. So, the PDAF needs to be more intelligent and humanized, there are some popular solutions to face the challenge.

The first is eye-contact auto-focus technology invented by Canon company. The first time the technology was used was in 1992 on film DLR camera eos5QD. At that time, eye contact autofocus was not a mature technology, so Canon company canceled it until September 2021. Flagship mirrorless camera eos R3 carries brand-new eye-contact autofocus technology and become such popular.

The principle of eye contact autofocus is reflection detection. Canon company installs infrared lamps in the viewfinder. The eye‘s cornea will reflect infrared rays when the user looks at the viewfinder. Then sensors can detect reflected rays by the cornea to define the position of the pupil and line of sight. In the electric viewfinder, the target of sight will be marked and perform autofocus. So, the camera's target can be controlled just by the user's line of sight.

Canon company has installed the eye-contact autofocus technology into newly released advanced cameras eos R5mark2 and eos R1. Although a few users reported that eye contact is not always effective and sensitive, most photographers realize that technology raises their work efficiency obviously.

The second is a combination of PDAF and artificial intelligence (AI). Canon company and Sony are the pioneers in using AI technology in cameras in recent years. Built-in AI can analysis focus targets and make the most reasonable decision in a very short time. Cameras can not only identify human beings, but also the car, bird, plane, and others in complex environments. AI technology enhanced the success rate of autofocus again in the fourth industrial revolution.

2.5. Hybrid Auto-focus Technology

Combination of PDAF and CDAF technologies. Today hybrid autofocus technology is widely used in camera industries. It has the advantages of both PDAF and CDAF, avoid its disadvantages at the same time. The PDAF is usually used to quickly auto-focus. After finding the correct focal point, the camera will use CDAF to check it. In the future, hybrid autofocus will be the mainstream. What’s more, some companies will probably combine DFD technologies and AI PDAF.

3. Conclusion

This article reviews the phylogeny of autofocus at first, pointing out that several companies and scientists make hard effects for it. Then, remember that the two most popular auto-focus technologies are CDAF and PDAF. PDAF is more advanced than CDAF, but it still has disadvantages. At last, the article introduced DFD, eye-contact autofocus, and AI focus. Auto focus in the future will be more intelligent and humanized.

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