Scholar Publishing Group
International Journal of Big Data Intelligent Technology
https://doi.org/10.38007/IJBDIT.2024.050108
ISSN 2790-0932 Vol. 5, Issue 1: 61-69

Review of Development and industrialization of Infrared Continuous Zoom Lenses

Yingping Bai[1,a], Weiling Cai[2,b], Ludan Mao[3,c], Tao Sun[4,d], Xie Ma[4,e], Weihong Zhong[1,f,*], Xiushui Ma[1,g,*]

[1]*NingboTech University, Ningbo 315100, China*

[2]*Donghua University, Shanghai 201600, China*

[3]*Ningbo SUNNY Infrared Technology CO., LTD., Yuyao 315400, China*

[4]*Ningbo University of Finance & Economics, Ningbo 315175, China*

[a]*3459951916@qq.com*, [b]*1835511648@qq.com*, [c]*15067548759@qq.com*, [d]*871522458@qq.com*, [e]*maxie@163.com*, [f]*zwh@163.com*, [g]*mxsh63@aliyun.com*

[*]*corresponding author*

Keywords: Infrared, Continuous Zoom, Development Status, Strategy and Suggestion

Abstract: This paper introduces the working principle of continuous zoom lenses, the research status at home and abroad, and the existing problems. Aiming at the existing problems, strategy and suggestions to solve them are put forward from the aspects of industrial upgrading, technological transformation, military-civilian integration, and cooperation among enterprise, university, research institute and user.

1. Introduction

Infrared continuous zoom lenses adjust the focal length of the entire optical system by changing the position of different optical components, achieving continuous, don't lose frame signal, and sustained zooming. They can quickly locate and track targets, making them increasingly popular in military, medical, disaster prevention, and other fields. They are a hot and challenging topic in both theoretical and applied research. This paper starts with the working principle of infrared continuous zoom lenses and provides a comprehensive review of their development and industrialization, offering a reference for researchers and practitioners in related fields.

2. Infrared Continuous Zoom Lens Working Principle

2.1 Infrared imaging technology

Infrared imaging technology is the use of infrared radiation with thermal radiation characteristics of infrared specific wavelengths of light signals converted into human vision can be observed in the image, can be observed beyond human vision of the object, Figure 1 is the principle of infrared imaging system block diagram.

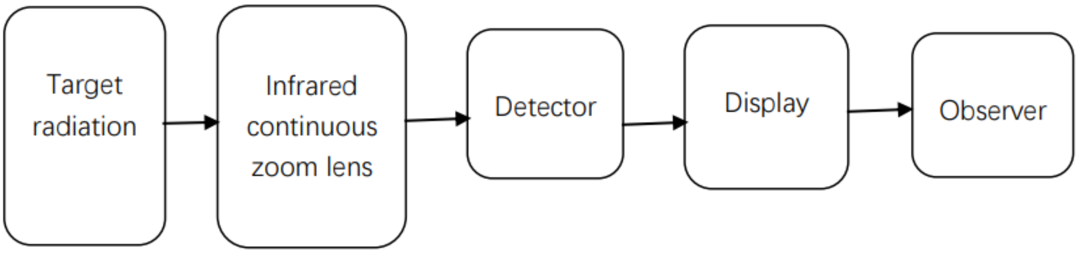

Figure 1. Schematic diagram of the infrared imaging system

2.2 Infrared Continuous Zoom Lenses

2.2.1 Working Principle of Continuous Zoom Lenses

The working principle of a continuous zoom lens is that the focal length of the optical system can be continuously changed within a certain range, but their image plane remains unchanged. When the light focus cannot be changed, the focal length of the system is changed by altering the spacing between the various variable components, which is the working principle of infrared zoom lenses. Generally, an infrared zoom optical lens can be divided into four parts: the front fixed group, the rear fixed group, the variable magnification group for zooming, and the compensation group [1,2].

2.2.2 Classification of Zoom Optical Lens Compensation

(1) Optical Compensation

The principle of optical compensation zoom lenses mainly involves using mechanical structures to connect moving components to perform linear motion, changing the spacing between moving and fixed components, thus achieving zooming. The most prominent feature of this compensation method is the addition of a fixed group between moving components to ensure image quality when the focal length changes. Since the motion of the variable magnification group is linear, its zoom structure is relatively simple. However, this optical system cannot achieve continuous changes in focal length and can only zoom at a few discrete points. This compensation method is only suitable for optical systems with a small magnification ratio. If this compensation method is used to design a zoom system with a short optical path and a large magnification ratio, it will result in a significant image plane displacement [3].

(2) Mechanical Compensation

In a mechanical compensation zoom system, the positions of the front and rear fixed groups remain constant during zooming. The variable magnification group changes the focal length through linear motion, and the compensation group moves non-linearly relative to the variable magnification group to compensate for the image plane displacement caused by the movement of the variable magnification group. For mechanical compensation zoom systems, there are two types of compensation: positive group compensation and negative group compensation [4,5].

Positive group compensation involves a compensation group lens with a positive focal length. This structure results in a relatively slender optical system with a larger field of view and a larger magnification ratio. For negative group compensation, the focal length of the compensation group lens is negative, which makes the overall optical structure length shorter and relatively simpler, mainly suitable for zoom lenses with a small field of view [6,7].

(3) Dual Group Linkage Compensation

The dual group linkage compensation method integrates the advantages of both optical compensation and mechanical compensation methods. On the basis of the optical compensation method, the fixed lens that is sandwiched between the two variable magnification groups is changed to perform nonlinear motion to compensate for the image plane movement caused by the movement of the variable magnification groups. Its greatest advantage is that when observing close-range targets, the field of view angle and effective aperture do not increase [8]. The structure of this compensation method is relatively complex, and it is quite challenging in terms of mechanical design and processing and adjustment.

3. Development and Industrialization circumstances of Infrared Continuous Zoom Lenses at Home and Abroad

3.1 Foreign Development and Industrialization

Hughes Company, targeting missile detection, designed a long-wave infrared zoom lens, which ensures that the infrared light transmission rate is above 50% with its excellent design, and the infrared zoom lens also has a high resolution [9]. To test the infrared imaging system, Lockheed Martin Company designed a mid-wave infrared zoom scene simulator, the characteristic of which is that the transfer function of the optical system has approached the diffraction limit [10]. R. L. Sinclair designed an infrared refractive zoom lens, using a secondary imaging structure to reduce the size of the objective and achieve cold aperture slot efficiency [11]. Teledyne Brown Company applied the designed system to the lens of an infrared-guided missile, using a diffraction surface to reduce the volume and weight of the system [11,12]. Figure 2 is the optical path simulation of a 20x zoom ratio lens by Ophir Company.

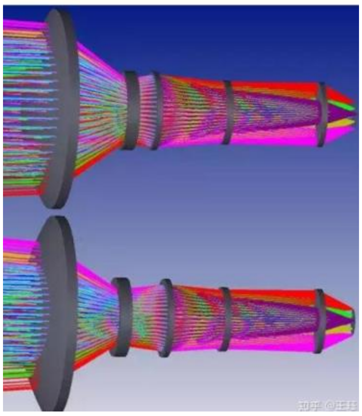

Figure 2. Optical path simulation of a 20× zoom ratio lens by Ophir Company

In Figure 2, the lens achieves a continuous zoom effect from 15~300 mm by switching between three optical paths. In addition to its high performance in the optical aspect, its mechanical structure is also quite complex. The system utilizes diffractive elements to ensure the lens can function normally within a range of temperature changes and provides good compensation for focus deviation caused by temperature variations.

Due to the application and development of infrared technology in the military field, the compensation method used in the zoom system for U.S. Navy aircraft during the zooming process is mechanical compensation. The zoom lens elements use aspheric lenses, which reduce the number of lenses in the system, thereby resulting in a high transmission rate.

With the rapid development of infrared optical materials and computer-aided processing technology, foreign infrared continuous zoom lens industrialisation process level continues to improve, as well as optical cold processing, precision machining, coating technology and other process technology level continues to progress for the development of high-performance infrared thermal imaging detection of high-zoom ratio of domestic technology to provide reference.

3.2 Domestic Development and Industrialization

China began studying infrared technology much later, only in the late 1980s and early 1990s. This was almost 100 years after some other countries. Besides, because foreign countries have been blocking our country technology, especially in the infrared detector embargo, leading to the slow development of infrared technology in China. Therefore, there is a large gap between China and foreign countries in infrared technology.

In recent years, with the increase of the research and exploration of infrared technology in China, some remarkable achievements have been made. Now, many places in China are studying infrared technology. For example, Tianjin Jinhuang Institute of Technical Physics, Beijing Remote Sensing Equipment Institute, Changchun Institute of Optics, Precision Mechanics and Physics, Chinese Academy of Sciences, Xi'an Institute of Applied Optics, Kunming Institute of Physics, and State Key Laboratory of Modern Optical Instruments, Zhejiang University are all working hard on this, Their research on infrared technology is also deepening, and has achieved certain results [13].

Chen Lüji and others conducted research on a cooling-type 320x240 staring focal plane detector, achieving continuous zoom from 27.5mm to 458mm [14].

Zhang Hongsheng and his team showed off a new kind of lens that can zoom in and out without stopping. By driving the corresponding variable zoom lens and the compensation lens back and forth along the slider, the compensation motor drives the secondary imaging lens by driving the focal adjustment ring, so as to realize the continuous zoom change of the lens. This structure design reduces the overall volume of the lens, is more convenient to use, and improves the resolution.

It moves special parts of the lens using a sliding block. A little motor helps to focus by moving another part of the lens. This makes the lens zoom smoothly, and it's also smaller and easier to handle. The lens has high imaging quality, high spatial resolution, small size and light weight [15].

Zhou Jiaojiao et al. invented a compact mid-wave infrared zoom lens and its imaging method, using only 7 lenses to realize the function of continuous zoom, zoom and scene pull blur imaging. The mechanical structure is designed with slide structure to ensure the stability of the image in the zoom process [7].

Zhang Liang et al. invented a three-group linkage compact high variable factor ratio infrared connection zoom optical system, The system adopts the double compensation group design method to realize the linkage of multiplier group and compensation group, realizing the large multiplier ratio. By adopting aspheric surface and diffraction surface, reduce the advanced aberration, axial point and axial point aberration, fine beam and wide beam aberration, and compress the axial space, and obtain satisfactory image quality in the full field of view and full aperture [16]. But, because the system has three parts to zoom, the optical system is complicated and the control precision is high.

Zhejiang University has designed a 3 x long-wave infrared zoom system, which can achieve a continuous zoom of 32mm~96mm. The design band is 8~12 μ m, the F number is 2, with 5 sets of lenses in the whole system, and the mechanical compensation method is used to compensate for the drift of the image plane. The front fixed group diameter is 94mm, the system total length is 159mm, the image quality is very clear [17-19].

Shunyu Optoelectronics Technology Co., Ltd. has made significant progress in the development of infrared continuous zoom lens technology, and four types of infrared lenses have been industrialized. The first one is an infrared consumer lens, as shown in Figure 3. It has a wide field of view angle, is compact and small, and has a low cost, can achieve real-time supervision, widely used in mobile phone accessories, outdoor sports and intelligent buildings, as shown in Figure 4.

Figure 3. Infrared consumer lens

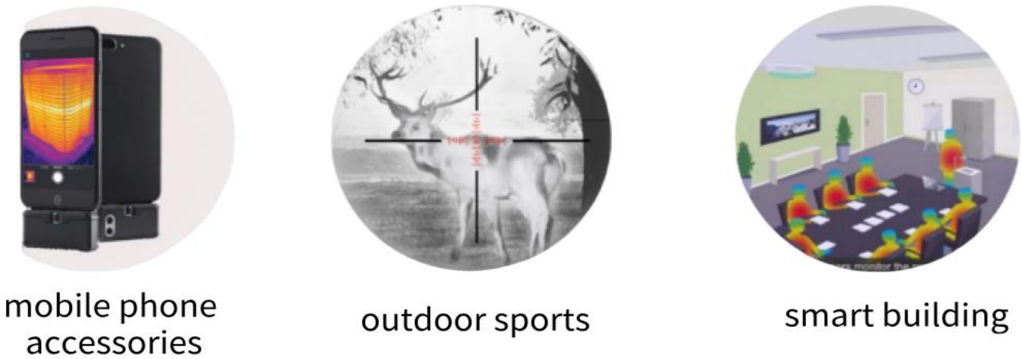

Figure 4. Application of infrared consumer lens

The second product is an infrared vehicle-mounted lens, as shown in Figure 5. It can recognize cars driving on the road and has been very useful in dealing with traffic accidents, as shown in Figure 6.

Figure 5. Infrared vehicle-mounted lens

Figure 6. Infrared vehicle-mounted lens for vehicle recognition

The third product is an infrared temperature measuring lens, as shown in Figure 7. The lens is applied in online fault detection, human body temperature measurement and product quality control and detection, as shown in Figure 8.

Figure 7. Infrared thermometric lens

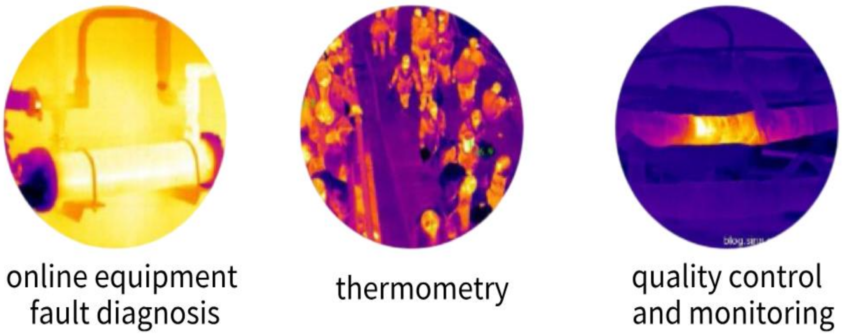

Figure 8. Application of infrared thermometric lens

The fourth product is an infrared security lens, as shown in Figure 9. Infrared security lens not only strong reliability, large field of view search small field of view positioning, but also all-weather monitoring, wide monitoring range. In addition, salt fog resistance, wind and sand resistance, in the safety hazard monitoring, forest fire monitoring and early warning and other aspects of the application , the lens has obvious advantages, as shown in Figure 10.

Figure 9. Infrared security lens

Figure 10. Application of infrared security lenses

Based on the research results of various infrared zoom lenses at home and abroad, infrared zoom lens has been widely paid attention. With the continuous progress of optical cold processing and other technologies, the excavation of new infrared materials and the improvement of lens surface shape, infrared zoom lens is developing towards the direction of miniaturization and lightweight, and the imaging quality is getting better and better.

4. Existing Problems and Solve the Problems Strategy and Suggestion

4.1 Existing problems

First, there's more competition because companies from other countries that make special lenses for the military are now making them for things like security cameras and cars. They're trying to sell more in our country by working with local companies and offering lower prices.

Secondly, the industry technology update and upgrading is accelerated, which has high requirements for enterprise research and development investment. China is facing the challenge of rapid upgrading of new products and new technologies and higher standards..

Finally, the talent shortage and rising costs restrict the development of the industry. The optical lens industry is both technical and labor-intensive, relying on optical design, precision manufacturing and other core technologies as well as related professional knowledge talents. China's current supply and demand of the labor force structure contradiction is prominent, can not all meet the needs of the optical lens industry high-tech talents.

4.2 Strategy and suggestion

(1) In terms of optical lenses, enterprises can upgrade their products according to the market demand, adopt differentiated development strategies, and seize the commanding heights of the market.

(2)Accelerate the pace of enterprise technological transformation, to achieve in the competition beyond the opponent, which through interdisciplinary integration and the introduction of advanced technologies.

(3)Under the guidance of the government, enterprises can layout the whole industrial chain and coordinate the development of military and civilian integration.

(4)We will strengthen cooperation between enterprise, university, research institute and user, promote technological upgrading and improve the overall competitiveness of the industry through personnel training, scientific research and industrial application.

5. Summary

This paper introduces the work principle of the infrared continuous zoom Lens, the research status at home and abroad, and the existing problems. Aiming at the existing problems, strategy and suggestions to solve them are put forward in aspects such as industrial upgrading, technological transformation, military-civilian integration, and cooperation among enterprise, university, research institute and user.

Acknowledgements

This paper is supported by Projects of major scientific and technological research of Ningbo City (2020Z065, 2021Z059,2022Z090(2022Z050), 2023Z050(the second batch)), Major instrument special projects of the ministry of science and technology of China(2018YFF01013200), Projects of major scientific and technological research of Beilun District, Ningbo City(2021BLG002, 2022G009), Projects of engineering research center of Ningbo City (Yinzhou District Development and Reform Bureau [2022] 23), Projects of scientific and technological research of colleges student's of China(202313022036).

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