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Technology Development and Application of IR Camera: Current Status and Challenges

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Abstract: Infrared cameras (i.e., IR cameras) are digital imaging devices that are sensitive to electromagnetic waves with wavelengths ranging from 0.76μm to 1000μm. With the rapid advancement of infrared imaging technology, optics manufacturers continue to enhance their products to compete in high-demand areas. Technological and application feasibility has driven the demand, so IR cameras and other thermal devices have been at the forefront of the market. IR cameras have been used on various occasions, such as military, security, automatic driving, industrial manufacturing, smart home, etc. In this paper, we mainly introduce the application status of IR cameras and infrared technology at home and abroad, provide an in-depth analysis of the global infrared camera market, illustrate the market dynamics and growth opportunities for infrared products, and forecast the challenges and market prospects, which are helpful to gain insights into the competitive landscape, as well as the product innovation and strategies of the major participants.

1. Introduction

The visible light that the human eye can see is arranged from long to short according to the wavelength, in order of red, orange, yellow, green, cyan, blue, and purple. The wavelength range of red light is 0.62 ~ 0.76μm, and the wavelength longer than red light is called infrared light. Infrared light has a wavelength between 0.76μm and 1000μm, which is located between radio waves and visible light. An IR Camera or infrared camera is a non-contact device that detects infrared energy (heat) and converts it into an electronic signal. The electronic signals produced by IR cameras are usually processed into thermal images or video displays, which are widely used in military, national defense, automatic driving, industrial manufacturing, public safety, economy, and other related fields.

2. Development of Infrared Technology

Originally developed for military use, IR cameras have been widely used in other fields. Benefiting from the growing demand for infrared monitoring in a variety of industries, thermal cameras are gradually becoming less costly and enabling more uses. These applications include security surveillance, intelligent transportation, commercial and residential security, threat detection in autonomous driving, and many more [1, 2]. Figure 1 shows the different stages and key

achievements of the development of infrared imaging technology.

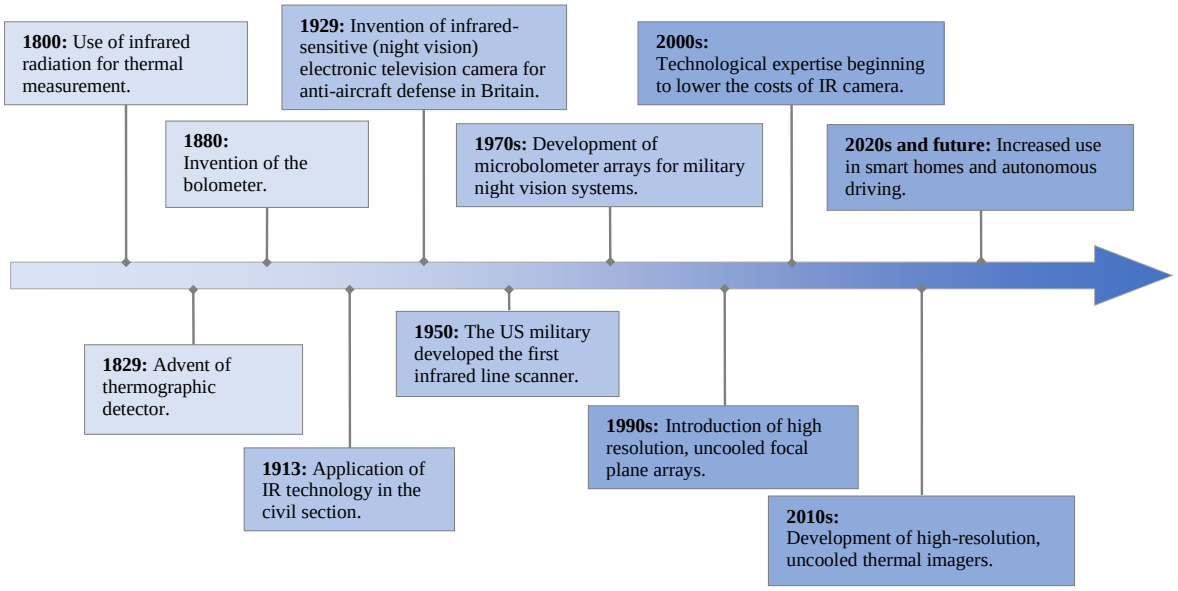

Figure 1: Different stages and key achievements in the development of infrared imaging technology.

3. Application at Home and Abroad

Early IR cameras were mainly deployed by the military and defense industry for border patrol and border security, and these cameras were mostly used for surveillance of airborne, maritime, and land systems. In recent years, the demand for IR cameras for reconnaissance, remote monitoring, security prevention, and control of critical infrastructure and equipment observation tasks has also increased in our country, powerful IR cameras and thermal zoom cameras are becoming more and more indispensable. The global infrared thermal imaging market revenue share in different segments is presented in 2021 as shown in Figure 2 [3].

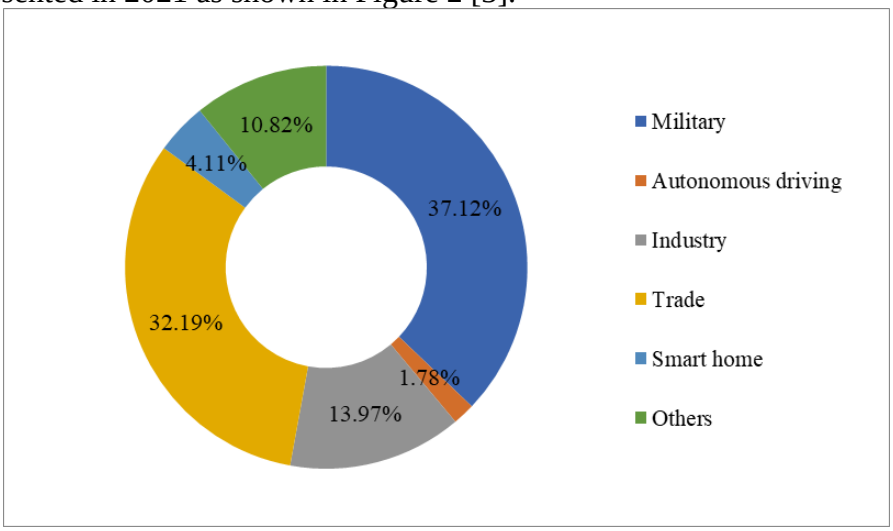

Figure 2: Share of the global IR camera market by segment in 2021 (%).

3.1. National Defense and Military

The most important use of IR cameras is for security systems in the military domain, especially

for intelligent signal detection and threat warning [4]. The low speed and low electromagnetic signatures of small unmanned aerial vehicles (UAVs) cannot be detected by acoustic sensors or radar, making more advanced technologies such as infrared technology the best option to prevent these new threats from harming humans or damaging critical infrastructure [5]. According to the Federal Aviation Administration (FAA), the number of UAVs flying in the United States will reach 30,000 by 2020. To monitor these UAVs flying over critical domestic infrastructure, research on intelligent detection and tracking of infrared targets is necessary and urgent.

Surveillance has been the main military application of IR cameras. In January 2020, HGH Infrared Systems, a French-based optoelectronic and infrared technology company launched SPYNEL panoramic wide-area surveillance cameras designed to protect onshore and offshore platforms from multiple threats emanating from the open ocean or isolated areas.

In April 2020, FLIR Systems Inc., based in Wilsonville, Oregon. Launched the FLIR Ranger HDC MR HD Mid-wave Infrared (MWIR) border security surveillance system to combat unmanned aerial Vehicles UAVs, illegal drug smuggling, and human trafficking. Ranger HDC MR Can detect illegal activity even in adverse weather conditions, using embedded computational analysis and image processing to reduce cognitive workload and enable operators to quickly distinguish between real threats and false alarms.

In July 2020, the European Commission's European Defence Industry Development Programme (EDIDP) allocated €30.6 million to the iMUGS project for the development of unmanned ground systems. This is one of the Commission's most important defense investments. The Integrated Modular Unmanned Ground System (iMUGS) project is being implemented by a consortium led by Milrem Robotics, which will work with 11 high-tech defense companies, including multinational technology company GMV.

In January 2021, the Indian Army signed a contract with Idea Forge India for the procurement of an unknown number of high-altitude variant UAVs at a cost of around $20 million. The fixed-wing drone is capable of vertical take-off and landing and can be deployed at high altitudes and in harsh environments for day and night surveillance, the company said.

The Defense Advanced Research and Projects Agency (DARPA) has launched a program to develop infrared technology or "stealth headlights" for navigation in low visibility conditions to evade enemies, seeking to discover and quantify information contained in ambient thermal radiation in various environments.

The UK Department of Defense (mod) has enhanced the MX-15's validation capability and reliability by using L3Harris T technology to provide 40 WESCAM MX-15 electro-optical, infrared (EO/IR) imaging systems that provide high-resolution, stable, full-motion intelligence information to support low-altitude tactical to high-altitude, ultra-long range sustained missions.

The development of night vision systems has become an important component of modern warfare, which typically utilizes infrared technology in grates to find warm objects on the road [6]. The ability to visualize in night conditions enables military exercises and brings potential advantages to forces equipped with the technology. For example, U.S. Army night vision experts are investigating the industry for high-resolution and wide-field long-wave infrared sensors to augment or replace the Army Driver Vision Enhancer (DVE) to help warfighters safely navigate vehicles at night and in reduced visibility conditions.

3.2. Autonomous Driving

With the increasing demand for advanced driver assistance systems (ADAS), the demand for IR cameras is expected to increase in the automotive industry [7]. In addition, governments around the world are encouraging the deployment of ADAS functions. For example, the U.S. Department of

Transportation's National Highway Traffic Safety Administration publishes federal Automated vehicle policies related to Highly automated vehicles (HAV), ranging from vehicles with advanced driver assistance system features to autonomous vehicles.

The use of IR cameras in cars is also increasing. According to statistics, 4,609 new passenger cars equipped with night vision systems were sold in China in 2019 alone. The brand models are mainly Cadillac XT5, XT6, and Hongqi H7, with an annual sales surge of 65.6%. Currently focused on developing mission-critical image sensors for ADAS and autonomous vehicle technologies, Dali technology and a handful of others are developing and mass-producing low-cost infrared thermal imagers.

Vision-based ADAS mainly identify and track potential hazards on the road while providing real-time vision-based analysis to the driver. This indicates an increased investment potential in the automotive sector, mainly in camera modules. FLIR, an Us-Based thermal imaging hardware company, added IR cameras to Level 4 autonomous vehicles in 2021. The company has partnered with Veoneer, a Swedish self-driving technology company that will use FLIR's IR cameras in its self-driving cars. The FLIR's thermal camera is known to recognize people up to 200 meters away and can also provide further information by capturing 360-degree images around the vehicle. Level 4 autonomous vehicles can autonomously recognize other vehicles, traffic signs, and some potential hazards on the road. Trucks with Level 4 autonomous driving are already being tested on public roads in the United States, but the vehicles must also have steering wheels and human intervention systems. Veoneer's thermal sensing system uses an infrared camera mounted on the front grille of the car to sense a 0.1-degree thermal difference, resulting in a very detailed and accurate thermal image of the field of view in front of the vehicle.

In addition, there has been a rapid increase in demand for dashboard cameras and rear cameras for parking in cars recently. Dashboard cameras are used to detect driving safety, such as the BMW X5's dashboard-mounted camera can perform facial recognition to alert drivers of fatigue driving. Dashboard cameras are mainly used in high-end and luxury cars, which promotes the popularization and development of IR cameras in the automotive industry.

It is worth noting that although in our country, as well as the United States and South Korea, and other countries. The traffic recorder is legal, but some countries strictly restrict the use of traffic recorders. For example, countries such as Austria, Luxembourg, and Portugal strictly prohibit the use of dashcams or recording devices in public places. The market has been facing challenges due to these constraints. However, with the reduction of restrictions in several countries such as Norway, Italy, Denmark, the Netherlands, and Spain, the usage of dashcams is increasing, which contributes to the development of the infrared camera market.

3.3. Industrial Manufacturing

IR cameras in the industrial field provide instant and continuous temperature measurement and control during production. From night vision helmets, sight scopes, and security cameras to machine vision systems, IR cameras meet the needs of mission-critical and industrial applications. High-temperature monitoring infrared camera is widely used in metallurgy, glass factory, foundry, and cement factory combustion furnace. Infrared gas detectors are used in emission control, petrochemicals, explosives detection, and urban gas analysis.

Infrared thermal imaging is widely used in predictive maintenance. The Federal Energy Management Program Institute estimates that failure prevention using IR cameras can lead to 30% to 40% cost savings, resulting in a 35% to 45% reduction in downtime and a 70% to 75% elimination of failures. Worn components and faulty circuits usually emit abnormal thermal energy, which is shown as a hot spot on the thermal image. Many devices operate at temperatures that rise

or fall significantly before a catastrophic failure occurs. IR cameras are considered one of the best uses of IR cameras to help equipment maintainers immediately identify these hot and cold spots that may have potential problems, helping them avoid unexpected downtime and equipment damage.

Infrared temperature sensors are also used in the process industry for continuous temperature monitoring and control, as well as simultaneous real-time video surveillance and automatic image recording and storage to help users obtain valuable process information [8]. Fourier Transform infrared (FTIR) spectroscopy is a basic laboratory measurement to assess the condition of lubricating oils. This technique can determine several oil properties, such as oxidation, nitration, and soot content.

IR cameras are also dedicated to machine vision applications. In March 2020, Allied Vision Technologies, based in Germany, launched a high-resolution Alvium 1800 USB camera equipped with a powerful second-generation SONY CMOS sensor that offers a high price-performance ratio. In April 2020, FLIR launched its smart thermal infrared sensor solution for industrial monitoring and elevated skin temperature screening for monitoring equipment, production lines, and critical infrastructure, as well as screening for elevated skin temperature.

3.4. Public Safety

Advances in infrared imaging have led to the development of night vision cameras designed for infrastructure in low-lit areas that can monitor traffic and track suspicious activity. The public application of IR cameras mainly occurs in transportation hubs, such as airports, train stations, subway stations, ports, and long-distance bus stations, etc., for scanning passengers for abnormal body temperature. IR cameras are also installed at the entrances and exits of some large shopping malls and office buildings for employee scanning and workplace entrance screening. Equip public places and infrastructure equipment with infrared thermal imaging cameras that can remotely measure temperature, and match body temperature data with facial recognition systems, to establish a comprehensive detection and tracking system for novel pneumonia infections.

The development of China's infrared camera market not only benefits from the effective detection and prevention and control of the outbreak of infectious diseases made by the Chinese government but also benefits from the continuous breakthrough in the research and development and mass production of infrared sensors in China [9]. Blackview, a Shenzhen-based startup known for its rugged smartphones, partnered with U.S. thermal imaging giant FLIR in 2020 to launch a phone with a built-in infrared thermal camera.

In May 2020, Honeywell released ThermoRebellion, a system that combines advanced infrared imaging technology and artificial intelligence algorithms to perform a noninvasive initial screening of people entering premises and verify that individuals are correctly wearing masks or other protective equipment.

In December 2020, Panasonic i-PRO Sensors USA announced the launch of a new thermal camera solution to help monitor the health and safety of people entering the premises. The solution combines a MOBOTIX M16/S16 camera with a new plug-in for the Panasonic i-PRO Video Insight video management system to automatically detect when an individual's body temperature exceeds a preset threshold value and alert those involved.

In January 2021, Bosch announced the DINION IP thermal 9000 RM, a human skin temperature detection camera kit, which is a system for measuring surface temperature over short distances and without contact in indoor application scenarios. The whole system includes a DINION thermal camera (NBT-9000-F19QSM) based on a microbolometer, a VIDEOJET decoder 7000 (VJD7513) with embedded thermal analysis function, a temperature reference device (IBB-5000-35) and an easy-to-use keyboard (KBD-UX) F).

In addition, infrared (IR) cameras can also be used to estimate the distance of objects and to detect the presence or absence of objects. By connecting an infrared camera to an Arduino, an intruder alarm can be raised by combining the sensor onto the door post, and by registering the sensor, an object passing through the door can be detected.

3.5. Other Fields

In the past few years, smart homes have promoted the popularity of video surveillance systems in the residential sector. Surveillance systems in this area have a variety of applications, such as surveillance and access control, and are additionally equipped with functions such as motion detection and night vision. Smart home projects are growing and leading to increased market demand. The Indian government plans to create 500 smart cities in phases, with smart homes being the most critical part of smart cities [10].

The current smart password locks used in the smart home mainly have the following security flaws, such as password leakage, weak passwords, unencrypted data, and insecure Internet gateways, which have become the key factors for the adoption of real-time video surveillance cameras in the smart home. An infrared camera can automatically control the electronic and electrical equipment in the home and can realize remote control through wireless communication, so it is widely used in a home automation system. Infrared sensors detect signals from light, motion, temperature, and other sensing elements and then send them to the main control device.

Rescue and firefighting, maritime, healthcare, and commercial activities, among others, hold a considerable market share in the global market. The growing number of autonomous ship projects across the globe will drive the demand for high-end IR cameras that help ships navigate in poor visibility conditions and perform night missions. IR applications are also widely adopted in commercial maritime applications. For example, FLIR Systems' MD series, MS series, Voyager series, and MU/MV series of IR cameras are provided to many private fleets and fleets. Italy's Genoa Navigator, Norway's NSSR, and Italian shipbuilding company Ferrati Group are the company's main maritime customers.

Significant innovations in handheld and mobile IR cameras have enabled fire and rescue teams to mount them on remote vehicles or carry them to the scene to identify fire sources and develop action plans based on this data. Personal vision systems are also expected to grow substantially during the forecast period due to the decreasing cost of infrared devices and the emergence of low-cost MEMS-based products.

Hospitals and medical institutions can use video surveillance systems to monitor the physical environment around the clock, greatly improving safety and operational efficiency. The IR camera and RGB camera can be used to measure the heart rate signal, and its 3D depth sensor is used to obtain the human respiratory signal to correct the initially calculated heart rate variability and respiratory sinus arrhythmia.

4. Challenges and Trends

In the past few decades, the advances in silicon technology have led to great changes in the development of infrared sensor technology. Thermal imaging provides valuable physical information beyond the visible light of an object, such as temperature, shape, composition, and location, so IR cameras are expected to be a key component of devices for various applications in the future. The COVID-19 epidemic has further changed the application situation of IR cameras because they can sense human body temperature. Combined with different applications, infrared imaging technology will obtain more and more unique use scenarios in different directions. For example, IR cameras are increasingly used in border control applications thanks to accurate motion

detection and surveillance techniques.

The domestic infrared camera industry and the internal market demand of the ecosystem are constantly improving, and the technical development at the present stage has met the domestic demand for thermal imaging systems and has been extended to some foreign areas with the application of epidemic prevention. However, Western countries have been much slower to adopt thermal cameras in public than China due to privacy and data leakage concerns.

The increasing popularity of non-cooled systems can be attributed to their compact design and energy-efficient low-maintenance operation. In September 2019, the U.S. Marine Corps mentioned partnering with L3 Harris to upgrade its helmet-mounted night vision system. Uncooled IR cameras collect light in the 8μm to 12μm spectral band with bandwidths from 3μm to 5μm and beyond, providing bands that more easily penetrate smoke, dust, water vapor, etc. With the increasing availability of affordable uncooled infrared imager products, many other application areas have been opened up in addition to traditional applications, such as smartphones. However, camera-related inaccurate measurements and image color issues are challenging the market growth.

5. Conclusion

In the next few years, it is expected that IR cameras will be part of various applications. For example, advanced infrared target detection technology is used for motion detection and surveillance. Many optics manufacturers are investing heavily in R&D programs to provide improved air and ground surveillance capabilities using advanced thermal imaging and drone technology. In the future, thermal cameras are likely to be integrated into various smart devices, such as running on smartphones, smart wristbands, and limousines. Anyway, the continuous improvement of these handheld, portable, and mobile integrable modules needs to be driven by research into further improvements in thermal performance.

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