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Application of Infrared Imaging Technology and Development of Countermeasures in Disaster Monitoring and Emergency Search or Rescue in Urban Underground Spaces

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Abstract: Urban underground spaces are one of the fastest growing areas in global engineering construction and commercial operations. The scale and level of China's urban underground engineering have advanced considerably, but accidents in urban underground spaces have also significantly increased; the necessary security monitoring and emergency rescue measures are seriously lacking. This paper focuses on security issues pertaining to terrorism, explosions, and nuclear, biological, or chemical attacks in urban underground spaces. This paper also analyzes the challenges faced by infrared imaging technology when implemented in disaster monitoring and emergency search and rescue. Key technologies and applications presented include shortwave infrared imaging, multi-scale infrared imaging preprocessing, adaptive image enhancement, adaptive infrared environment imaging, and disaster location and alarm. This paper discusses the applications of infrared imaging technology in underground space emergencies, such as fires. The research presented here can provide guidance for security legislation and strategic planning of urban underground spaces in China.

Keywords: infrared imaging; disaster monitoring; emergency search and rescue; countermeasures; urban underground space

1 Introduction

Public safety in urban underground spaces is highly relevant to overall national security. The sealed space and dense population within underground spaces intensify public safety accidents [1]. Therefore, disaster monitoring and emergency search & rescue are essential problems to be solved to guarantee the safety of urban underground spaces. The mission is to prevent terrorist bombings during normal times or to cope with nuclear, biological, and chemical (NBC) raids during extraordinary times.

Infrared imaging technology has gained attention in developed countries and has become an important signal of national development level and technology strength due to its wide range of military and civilian applications. Infrared imaging technology can utilize temperature differences between targets to form images and detect the temperature changes of all targets in a site without lighting [2]. It is extremely suitable for real-time monitoring and effective observation during emergency search & rescue after explosions or fires. Therefore, developing further applications of infrared imaging technology in underground spaces is an urgent demand to guarantee safety.

2 Current situation of urban underground space safety

On the one hand, urban underground spaces possess much

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higher defensive capabilities against earthquakes than buildings above ground, on the other hand, some other catastrophes like fires and explosions [3] may cause much more serious damage to urban underground space compared with above-ground urban areas. This dual character requires us to fully exploit the anti-disaster capabilities of urban underground spaces, as these spaces are likely to become important for protecting urban residents from natural and military catastrophes. Special attention should also be paid to research into technologies that can prevent or minimize losses from disasters, such as fires and explosions in underground spaces.

Urban underground space has become the fastest growing global construction and commercial operation market. The standard and scale of China's urban underground construction have developed considerably. The number of accidents occurring in urban underground spaces has also increased significantly. Security monitoring and emergency rescue are seriously lacking.

Although there has been relatively thorough monitoring system in urban underground spaces with smart monitoring centers and video monitoring systems in important areas, these monitoring systems only use charge coupled device (CCD) cameras. In addition, there is a lack of specific data for population monitoring. As a result, when a disaster occurs, an underground video monitoring system will not function completely during power failures. Furthermore, they cannot detect the origin of a fire or explosion and cannot provide sufficient warning time.

Once a disaster occurs, the priority is to obtain on-site information through multiple channels. However, when explosions or fires occur in an urban underground space, the low light, dense smoke, and high temperature will disable emergent rescue equipment. A fireman's head lamp and single infrared fire sensor used within fireplaces cannot identify people and objects in smoky and low light conditions, thus resulting in casualties for firemen. Since the use of large rescue equipment in an underground space is limited, the requirements for search and rescue capabilities are high. Right now, search and rescue capabilities of smoke sensor equipment are insufficient due to the lack of an infrared thermal imager.

3 Infrared imaging technology application and challenges

Underground spaces create surveillance difficulties, safety hazards, and serious consequences from accidents. Thus, adopting advanced infrared imaging technology is necessary given the special circumstances.

3.1 Application of infrared imaging technology

Compared to an ordinary visible light imaging, infrared imaging technology the potential to improve safety in urban underground spaces. A infrared imaging device does not require visible light. It can gather precise temperature difference images in darkness, and precisely measure the temperature of people and objects within the field of view. It also has the ability to penetrate smoke and dust to form images. Meanwhile, it has low power consumption, light weight, and supports network surveillance with image sharing in real time. Infrared imaging technology is an intrinsically safe product.

Infrared imaging technology has the following applications in urban underground spaces: urban metro/railway transportation safety surveillance; safety monitoring of targets at air-raid shelters, parking lots, transportation junctions, and other huge underground spaces with low illumination levels; damage detection in oil/natural gas/water/heating pipelines; detection of short/open electrical circuits; emergency rescue equipment for explosions and fires; real-time monitoring of underground spaces; surveillance in underground public spaces.

3.2 Urgent application problems in special circumstances

Currently, local and foreign researchers are paying attention to the internal elements of infrared imaging equipment, such as the focal plane array detector, algorithm design, and coated lenses. However, they focus less on how external elements influence imaging quality, especially influences from high temperature, dense smoke, dark environment, and panic during a catastrophe.

3.2.1 Influence of low illumination level in urban underground spaces

A monitoring system plays an important role in the development of underground spaces, as well as in disaster prevention and disaster relief. Underground spaces create obstacles to monitoring under natural illumination. As a result, the selection of illumination and monitoring design must receive special attention. However, when fires, explosions or NBC attacks occur, electrical equipment is usually damaged. Even if a standing emergency light is not broken in a closed space, the underground space could have a low illumination level during fires or explosions, or when dust and smoke are present. Since this low illumination level may not satisfy the illumination requirements for CCD monitoring, this monitoring equipment will fail. Therefore, a monitoring system that uses an infrared imaging detector as a terminal will have higher requirements for smoke penetration and low power consumption to be used in such environments.

3.2.2 Influences of confined spaces and high temperature caused by explosions and fires

Underground spaces are relatively confined. Diffusing dense smoke is difficult when fires or NBC attacks occur. Further damage caused by secondary explosions threaten detained people or the lives of rescuers. In addition, all kinds of emergency rescue equipment must be reliable at high temperatures. These elements bring especially high requirements for the adaptability of infrared imaging equipment.

3.2.3 Influences of high temperature, smoke, and noise during the initial stage of disasters

The initial stage of a disaster often brings high temperature and thick smoke, resulting in the formation of a thermal barrier. At this time, long-wave infrared imaging equipment cannot clearly survey the disaster situation. In particular, the location of a fire and the nearby area are covered by dense smoke, which inhibit the usefulness of detection equipment. Therefore, special short-wave infrared imaging equipment must be developed since it is not influenced by high temperature and can penetrate smoke.

3.2.4 Crowds, dispersity, and lack of regulation

Urban underground spaces have few entrances or exits. Evacuation is difficult if people and vehicles are crowded in an underground space. The number of people will increase in the area close to an entrance/exit underground space entrance/exit when a disaster or accident occurs, thus blocking the pathway and causing casualties. In contrast, rescue forces can conveniently reach disaster sites when similar disasters or accidents occur above ground. Fire trucks, ambulances, and helicopters can arrive directly to start rescue operations. In underground spaces, however, many rescue forces like some firefighting equipment cannot arrive on time. Therefore, personal rescue ability becomes extremely important. That is to say, the use of an infrared monitoring system can effectively improve anti-disaster monitoring results and safety in urban underground spaces. Meanwhile, easy-to-carry highly sensitive infrared detection equipment can improve search and rescue capabilities of police and firemen after an explosion or fire, protecting the lives and property of civilians, reducing disaster loss, and improving protection for rescue forces.

4 Key technologies of infrared imaging

Hot smoke produced by burning construction materials contains many different compounds, including inorganic toxic gas, organic toxic gas, tiny solid particles, condensed droppings, and remaining air. Tiny solid particles of radii between 0.01–10 μm are the products of incomplete combustion. Tiny solid particles can shield visible lights and reduce visibility during a fire.

After many years of development, the relevant infrared imaging technology has seen several breakthroughs in providing effective monitoring explosions and fires in underground spaces.

4.1 Short-wave infrared imaging technology

Short-wave infrared imaging has excellent target imaging capabilities in smoky, dusty, and other low visibility environments. Short-wave infrared (0.9–1.7 μm) radiation is an important atmospheric penetration window and can provide information that cannot be provided by visible light, middle-wave, or long-wave infrared radiation. Seamless detection in the three atmospheric infrared penetration windows (1–2.5 μm, 3–5 μm, and 8–14 μm) can be obtained. Therefore, short-wave infrared imaging plays an essential role in acquiring information and can be applied to various fields including transportation safety, climate observation and forecast, agriculture and forestry census, territorial resources exploration, environmental detection, and deep space & astronomical detection.

Short-wave infrared imaging can detect infrared light reflected from a target and generate visible videos. Objects are more distinguishable in these images. Compared to middle- or long-wave infrared light, short-wave infrared light can be used to form images at any time of a day. Moreover, short-wave infrared light can penetrate smoke, fog, and dust and be used to form images.

A short-wave infrared imaging device is a high-tech product that uses a combination of optics, semiconductor materials, microelectronics, precision machinery, and a display. Hence, it is a complicated technology that requires many resources to research and develop. In addition, developed countries have prevented these sorts of high-tech products from entering China. However, through China's own tracking study during these years, home-made products with proprietary intellectual property rights have seen several breakthroughs [4]. Advances include the focal plane detector, information display, image processing circuits, and control system. These advances offer improved digital imaging detail, enhanced digital images, black hot/white hot image parity, adjustable contrast and brightness, adjustable non-uniformity correction, and digital image sampling.

In an environment with dense smoke, tiny solid particles become suspended in air and can block visible light. However, longer wavelength light can penetrate dense smoke. Short-wave infrared imaging utilizes the 0.9–1.7 μm waveband. Although human eyes cannot identify infrared, the radiation can still penetrate smoke. In building fires, tiny solid particles that shield visible light are the product of incomplete combustion. Incomplete combustion occurs when oxygen density is lower than the oxygen index range of the combustible material, and the tiny solid particles are generated more easily at lower oxygen densities.

We conducted research into using short-wave infrared cameras for imaging to observe luminous and illuminous evacuation indicators during a smoldering timber, smoldering cotton rope fire, open diesel fire, and open polyurethane fire at the fire rescue laboratory [5], a key laboratory of the Ministry of Public Safety. To imitate the fact that an underground space can accumulate dense smoke within a short period of time, it is better not to design the same smoke generation system as an external firing model. Therefore, all firing and smoke simulations in this experiment were conducted in the middle of an internal smoke collection box. Fig. 1 shows the relationship between smoke density and image definition, where the image resolution is represented using an absolute central matrix (ACM). The results show that short-wave infrared light provides good detection stability when the density of smoke is relatively large.

4.2 Multi-scale infrared imaging preprocessing technology

Multi-scale infrared imaging preprocessing primarily solves two problems. First, it increases the temperature and space resolution ratio in the image. Second, it allows the dynamic range to be adjusted by using different channels to form images. We can penetrate fires and thermal fields, and we can creating clear images of essential targets by combing a multi-scale Retinex (MSR) algorithm and a bilateral filter (BF) [6].

In the MSR algorithm, the primary function of a small scale Retinex component is to improve image detail and condense the dynamic range. This functionality is very similar to using a bilateral filter to improve image detail. Therefore, we can replace SSR in the MSR algorithm with the BF output to avoid an incorrect estimate of light brought on by lack of detail information, which may cause the vignette effect. Essentially, BF is a high-pass filter with an edge protection function. A detailed component can be generated with a BF by selectively extracting detailed image information and improving image detail. At the same time, we can eliminate partial high frequency components in the high-contrast space and optimize the effect of the MSR algorithm. In particular, it can penetrate fires and create clear target images during a high temperature fire or after an explosion.

We conducted comparative research on image definition of using the 0.4–0.76 μm, 0.4–1 μm, and 7–14 μm wavebands during fires. The results are shown in Fig. 2, where image definition is represented by ACM. The results show that the size and density of smoke particles did not have major effect on the infrared image quality, regardless of illumination. The only element that influences image quality is the temperature difference between the target and external environment. The imaging environment is relatively complicated during a real fire with high temperature and dense smoke. Since different objects are composed of multiple materials, different materials have different specific heat capacities, heat is released from different burning objects at different rates, fires' and smokes' thermal interaction time to external environment is different when fire rescue forces arrive and many other reasons, infrared imaging equipment does not have a standard failure temperature. During real fires, when a high concentration of smoldering fires caused failure of short-wave and visible light imaging, only infrared imaging showed better results, as shown in Fig. 2. When the fire became large enough, the temperature difference between targets and the external environment became extremely low after thermal interaction with the fire or high-temperature smoke. At this time, long-wave infrared imaging and normal visible light imaging both failed; only short-wave imaging produced good detection results. Therefore, combing short-wave and long-wave infrared imaging technology can benefit from each other and be applied to more complicated fire places, effectively assisting fire rescue forces.

4.3 Advanced infrared imaging adaptive enhanced technology

An infrared imaging enhancement algorithm is an important method to effectively improve and strengthen the quality of infrared images, increase contrast, clarify the edges of objects, and obtain better image information. The enhancement algorithm results must directly influence the quality of the infrared images in real time.

A common image enhancement algorithm is to use histogram equalization. Infrared images receive target and background thermal radiation simultaneously. The temperature difference between the target and background is very low, making the gray difference between them low, and the temperature difference between some other high-temperature targets and background is extremely high, resulting in large gray difference between them. Using a histogram equalization method to improve infrared images either improves the background image or saturates

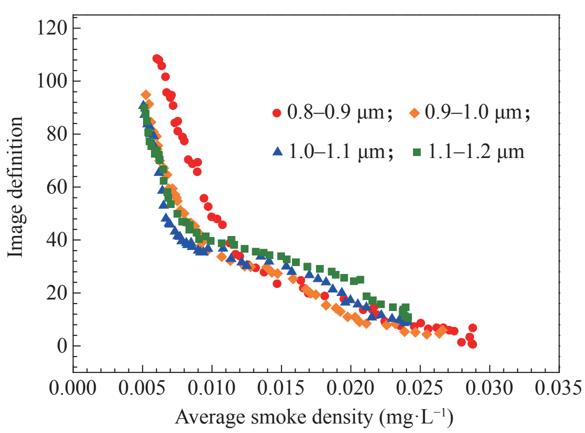

Fig. 1. Relationship between smoke density and image definition.

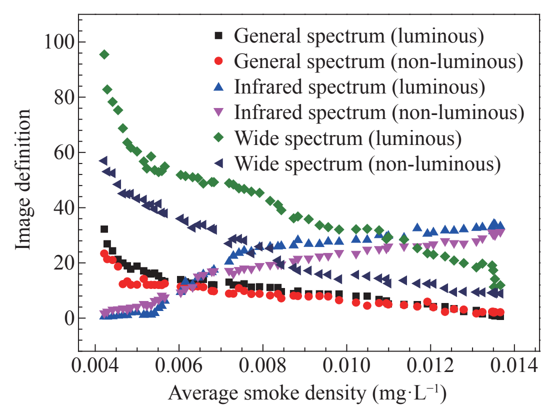

Fig. 2. Comparison of target image definition in different smoke densities detected by imagers with three wavebands.

high-temperature targets. A platform histogram algorithm can overcome the defects of a traditional histogram equalization algorithm. This requires selecting a platform value, which can effectively increase the background contrast. However, its calculation is so complex that it cannot be performed in real time, and image edges remain vague. Adopting an infrared imaging improvement algorithm that combines an adaptive platform histogram with edge improvement can adaptively select a histogram threshold value, improve edge quality, and be performed in real time in a complicated underground space [7].

4.4 Environment adaptive infrared imaging technology

Since the underground spaces are relatively confined, it is difficult for dense smoke to diffuse when fires or NBC explosions occur. A secondary explosion could exacerbate damages. Meanwhile, partial high-temperature burning could intensify environmental temperature changes. Dramatic environmental temperature changes create large non-uniformity in the focal plane pixel sensing temperature that seriously degrades imaging quality. In addition, a high environmental temperature affects equipment sensitivity, such that imaging equipment cannot capture accurate images. These factors create higher requirements for the environmental adaptation of infrared imaging equipment. Changes in the non-uniformity correction model required for background adaptive correction can be corrected by designing infrared imaging components as reconfigurable hardware. We can use a component processor to read from a precise temperature sensor in real time and choose different focal plane non-uniformity correction coefficients based on the local temperature to adapt to environmental temperature changes. The infrared imaging focal plane could adjust the dynamic range of its output signal by changing its bias voltage, thus further changing its sensitivity. Using precise program-controlled mode to set the bias voltage in the focal plane when designing hardware circuits for infrared imaging components can achieve these goals. Prior experiments have demonstrated the feasibility of the above methods [8].

4.5 Determine disaster's location and give alarm based on infrared imaging

One of the problems when fighting against underground fires is determining the origin of the fire. Since underground buildings and paths are complicated and have limited space, it is difficult to determine the origin of a fire in dense smoke, causing a missed rescue opportunity. Utilizing a pre-constructed geographical information system of the underground space, we can deploy and control an infrared imaging terminal with an electrical position label in an underground space. A distributed mesh infrared imaging terminal can cover the entire space. Since an infrared terminal is fixed and used as a base station, all targets within the observation area can be confirmed with the geographical information system.

To determine the presence of an abnormal case at a site in real time, we can embed target identification, hot origin tracing, and other imaging processing technology to the front end of the infrared imaging terminal to obtain a hot spot in an image. We can also use the temperature measurement function to measure the temperature of a hot spot and identify whether the absolute temperature of the hot spot is larger than a set limit value, or whether the temperature is increasing at a rate that is larger than the set threshold value. If there is an abnormal situation, the infrared imaging terminal could utilize internal low power consumption mesh networking components, effectively conduct self-organizing communication, and find a channel to communicate with the outside through multiple hop transmission. Since wireless mesh networking is set at the same time as the fire alarm system, its density is large enough to build a reliable communication system at the fire location and automatically transmit video, location, temperature, temperature increase rate, and other information to a command center. The situation could be monitored through a wireless autonomous network or wired network and alarms could be sounded in the vicinity.

5 Application of infrared imaging technology in specific areas

Infrared imaging technology is primarily used in research on underground disaster prevention systems and has shown significant improvements in terms of system stability. Specifically, results have shown progress in ultra-short wave infrared imaging components, multi-functional small-sized handheld infrared imagers, infrared fire-fighting helmets, and in other areas.

5.1 Multi-functional small-sized handheld infrared imager

Pipelines and electric cables in urban underground spaces require safety inspection tours at fixed hours to prevent leaks, fires, pipeline and cable breaks, and other natural disasters. Meanwhile, when searching for the origin of a disaster, providing rescue without electricity and under dense smoke and dust requires effective equipment in places with poor visibility. Utilizing a multi-functional small-sized handheld infrared imager developed upon infrared imaging technology to detect the disaster site can provide basic support for subsequent rescue and recovery tasks.

A multi-functional small-sized handheld infrared imager can provide real-time infrared imaging of various types of targets, record picture and video, and replay infrared video images. This product uses a battery as electricity source, so it can continuously work for a long time and has small size, light weight, is easy to carry, and can be maneuvered with one hand [9].

5.2 Fire-fighting helmet infrared imaging system

When an explosion or fire occurs in an urban underground space, the illumination system goes out of use without electricity. Dense smoke seriously influences the effectiveness of a normal fire-fighting helmet, makes it unable to help rescue forces detect the situation or implement effective rescue, and even threatens the safety of the fire-fighting forces. Utilizing an infrared imaging helmet can help rescue forces clearly watch fires, easily find paths to enter or exit the fire location, and decrease casualties.

This system utilizes infrared focal plane non-uniformity adaptive correction methods based on characteristic decomposition [10], sequential optimization of imaging parameters, and a pseudo-colorful image improvement algorithm based on a locally linear embedding algorithm [11]. Therefore, it improves the definition and layering of detecting images, allows fire fighters to use a helmet viewer to conduct high resolution, high-layered identification, record pictures and video, and use wireless transmission to connect with a command center. This system uses a battery as an electricity source, so it can continuously work for a long time. It is also light weight, shock resistant, and allows easy maneuverability. It uses a similar frame as a normal fire-fighting helmet.

5.3 Short wave infrared imaging rescue equipment in smoke

Modern war is a high-tech war under nuclear threat. The safety of an urban underground space requires preparation of military defenses against NBC strikes. In an urban underground space under attack from NBC strikes, there is usually plenty of defensive smoke release, and traffic volume is relatively high, so special rescue equipment has special traffic channel requirements. We can use an advanced short wave infrared imaging smoke penetration setup to detect, identify, and rescue civilians.

5.4 Population census infrared imaging terminal in the regulated area

Compared to the relatively confined underground spaces, a regulated area is usually more spacious. Accidents happen when people gather in large numbers and cause a stampede; therefore, the number of people in that area should be known. We need to design a population census imaging terminal based on infrared imaging in a regulated area to count people in each area of the underground space throughout the day. We could use infrared imaging and corresponding video streaming technology to analyze population flows in the video surveillance range, save and send to a command center, and create a real-time personnel report. The census precision is higher than 98%.

5.5 Networked test temperature monitoring system

Each urban underground subspace is narrow and dispersed. Since the properties of each subspace and function are different, their monitoring goals are different as well. Manual inspection is relatively difficult or ineffective for safety protection from sudden fires and explosions. Therefore, we can detect hidden threats and prevent crises from emerging by creating a networked test temperature monitoring system. This type of integral detection and infrared thermometry terminal could capture site images at any moment and measure a target's temperature variation simultaneously. It will automatically identify and send out alarms when it detects a target's abnormal temperature. This equipment utilizes high-speed parallel dataflow technology, sends image information to a synthesized integrated managing device, implements multipoint distribution network monitoring, and creates a networked infrared imaging monitoring system.

5.6 Dispersed infrared imaging safety monitoring system

To satisfy urban underground space anti-terrorism monitoring requirements, which is the ability to find and identify suspicious personnel around a monitoring location and invasion of explosive objects, provide acousto-optic early warning, measure a target's distance, speed, trace targets, and provide alarms simultaneously, connect with monitoring center and warning devices, and approximate speed in low illumination. Adopting infrared and visible light dual-spectrum video monitoring, synthesizing multi-spectrum imaging fusion processing [12], infrared imaging background adaptive improvement, and infrared focal plane adaptive correction technology, we can effectively strengthen the quality and reliability of infrared images in low illumination conditions. Infrared video monitoring is compact and has low power consumption. This system uses microwave wireless video to transmit, adopts dispersed terminal monitoring technology under synthesized integrated management, combines identification methods which combines a target's static and dynamic characteristics, builds a typical target feature library, allows target identification, quickly manages captured image data, collects real-time video and pictures, and greatly improves underground monitoring and rescue ability without illumination, or in dense smoke and high temperature conditions.

6 Development strategies

6.1 Perfect legislation to strengthen disaster prevention and control

Due to the special environment of underground space, loss from disaster could be devastating. With this being said, we should focus on research into early fire and disaster warnings in underground spaces [13]. As the key to disaster prevention is to prevent crises from emerging and contain accidents with increasing frequency, municipal departments (construction, transportation, railway, and fire-fighting) and industry departments must provide criterion and enact regulations addressing underground space safety protection. Although China has had certain relevant construction rules, these rules are not perfect and require strengthened disaster prevention and control measures, such as improving basic fire prevention methods, forcibly implementing infrared imaging technology with smoke penetration functions, and enact rescue and aid fire-fighting policies, among others.

6.2 Accelerate infrared imaging application research project approval

Since underground spaces have many unpredictable safety elements, exert big impact on environment and society, and require prevention and regulation technology, we suggest the national Ministry of Science and Technology to list *Suggestions for the Application and Future Development of Infrared Imaging Technologies in Disaster Monitoring and Emergency Search & Rescue in Urban Underground Spaces* as a technology support major special project during China's 13th Five-Year Plan, in order to start the research as soon as possible. This will increase input resources, focus more attention on low-cost infrared imaging components, and scale system production to popularize applications of infrared imaging technology.

6.3 Construct multilevel intelligent infrared imaging monitoring network

For disaster prevention and control in urban underground spaces, utilizing a fixed infrared imaging networked monitoring system to manage low illumination real-time monitoring, and provide early warning when disasters occur becomes especially crucial. For example, we could develop underground space safety monitoring and forecast technology, build an underground engineering information system, combine the experience of a group behavior psychologist, record real disaster scene, and utilize these resources to support emergent decisions-making or evaluate post-disaster loss [14]. Meanwhile, we could construct a long-distance monitoring system, obtain information through sensors and report to a command center, analyze real-time big data, and send out alarms in time and adopt an emergency plan.

6.4 Improve protection to rescue force equipment

Space environmental pollution may arise during a disaster in an underground space, causing an electricity interruption. However, effective and timely aid is necessary during rescue from explosion and fire disasters. Therefore, we must focus on research into individual equipment for rescuers (infrared helmet, hand infrared imager), since this equipment is necessary for rescue forces to inspect crises, evacuate from disaster site, and find an evacuation path. However, for the construction of underground spaces, the dangers involved in inspecting a disaster, we must strengthen research into rescue robots with infrared vision (autonomous rescue robot).

6.5 Pay attention to underground space image transmission

We should pay attention to research into infrared imaging technology and develop information transmission technology, combine multi-spectrum imaging with ground wave communication technology, accelerate research into a dispersed locatable infrared imaging terminal, and apply this to transmission of images generated by a real-time monitoring system. Meanwhile, we need to introduce modern Internet of Things technology to a real-time disaster monitoring system. A variety of disasters could occur in an underground space. Therefore, besides imaging sensors, we must utilize various types of sensors (biology, smell, vibration, smoke, and etc.) to implement real-time detection and ranging. The combination of these sensors could comprehensively monitor situations in underground spaces. In addition to multilevel monitoring and a surveillance network system in an underground space, we need to strengthen research relevant to underground space monitoring and proprietary surveillance technology and equipment so that situations in underground spaces can be known in real-time.

In conclusion, infrared imaging technology has a wide range of applications in safety and protection of urban underground spaces. As a key technology for a national strategic emerging industry, infrared imaging technology attracts tremendous attention. After tens of years of development of uncooled infrared imaging technology, domestication of its core detecting components has been enhanced. Infrared imaging technology generates images with stable quality, has a wide range of applications, can be produced in scale, and could provide effective imaging safety monitoring and satisfy basic emergency rescue requirements for protection of urban underground spaces when explosions or NBC strikes occur.

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