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A Review of Camouflage Object Detection Techniques

Hi Chia Ling, Kai Liang Lew*, Cheng Zheng, Tetuko Kurniawan, Suleiman Aliyu Babale and Chia Shyan Lee

***Abstract* – Camouflage Object Detection (COD) is a constantly evolving field that deals with the difficulties of locating items hidden in intricate settings. This review examines the progression of COD techniques, from classical human methods to physical component-based methods such as infrared, LIDAR, multispectral and hyperspectral detection. Key applications of COD span from military reconnaissance to wildlife monitoring, medical imaging, and disaster response, where the ability to detect concealed objects has transformative implications. Future research should prioritize integrating diverse data sources, refining machine learning algorithms, and overcoming deployment constraints to advance the field further.**

Keywords— Camouflage, Object Detection, Infrared, LIDAR, Multispectral, Hyperspectral, Human Vision

I. INTRODUCTION

Camouflage is initially just a natural phenomenon that Mother Nature has gifted to the flora and fauna to blend into the environment. Used by prey and predators alike, the occurrence of this phenomenon is mainly to avoid detection by changing their skin or disguising themselves as per their surrounding colour [1]. Millions of years have passed since the evolution of this amazing survival strategy which can still be seen today. Humans have taken notice and have been using this tactic since ancient times using animal parts, foliage and other concealment methods for hunting and protecting themselves [2] In 1914, a French artist named Lucien-Victor Guirand de Scévola and his friends, using their art expertise, initiated the development and usage of camouflage for military use during World War I which made it famous to this day [2, 3]. From that day forth, a constant and extensive evolution of camouflage for military use has persisted. With technological advancements and the nature of warfare that is always changing being its main driving force. However, camouflage is not only limited to warfare. In day-to-day life, numerous items and scenes can unintentionally brought about the illusion of camouflage caused by the limitations in human visual perception.

This is where Camouflage Object Detection (COD) comes into the picture. With the rise of advanced technologies, particularly in the fields of computer vision and machine learning, detecting camouflaged objects has become an interesting albeit niche area of research that has great hidden potential in technology of imaging. Being capable of recognizing targets that are purposely or perhaps even accidentally concealed in cluttered scenes is essential for a variety of real-life scenarios whether it be military surveillance, environmental maintenance, as well as everyday safety and security. It also plays an important role in the development of image recognition systems as a whole. As camouflage techniques grow ever so more

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sophisticated with each passing day, an increased urgency for the makings of more advanced detection systems are called. However, distinguishing concealed objects from their environments have proven to be challenging even for the current strides of COD technology.

This paper aims to provide a comprehensive overview of the current state of research in camouflage detection, focusing on the various approaches that have been developed and the challenges that remain. A synopsis of COD's recent developments, applications, current challenges and future directions. By examining the challenges and potential solutions, we hope to emphasise the significance of creating reliable systems which are capable of detecting camouflaged objects in a variety of situations by looking at the difficulties and possible solutions.

II. Background

A. Methodology

This research makes use of the internet to find papers regarding this topic. The websites used are ScienceDirect, Google Scholar, Papers with Codes. IEE Explore and other reputable sources. Most of the modern sources about the latest technology is within the last 10 years. However, regarding historical achievements and details, the search is expanded for historical research purposes. Most of the publications that are used are of the English variation as most of the information available are in English and it would be a tedious affair to translate from other language sources. Keywords such as Camouflage Object Detection, History of Camouflage, CNN models in COD and similar iterations were used to search for the papers used in this review.

As of any review paper, this paper too is not free of biases. It is limited to only English sources, contains only the most prominent results shown by the websites and due to limited time and resources to study a wider range of material, has less information regarding the true entire scope and field of the subject of Camouflage Object Detection.

B. Overview of Camouflage Object Detection

In the early days, humans relied on their innate senses and developed manual techniques to detect objects, especially to recognise potential threats or sources of food. Object detection, in this setting, was essential for survival and the hunter-gatherer way of life. The process involved a combination of sensory input, physical cues, and learned techniques for interpreting the environment. As time goes on, with the introduction of its usage in military contexts, the evolvement of the ability to detect and analyse objects, threats, or potential targets has become more and more complicated Early humans' survival instincts, which were chiefly concerned with detecting predators and prey in the ancient world, now have become the groundwork for military tactics [1]. As the world's society became more complex, the methods of object detection and communication were formalised by military forces for warfare. With the dawn of a new age after the war, computers were created, enabling humans to handle vast amounts of data and perform complex calculations at speeds that in a way were previously unprecedented for humanity. Since then, this technological development has changed every facet of human existence, including the capacity to identify, assess, and respond to objects in our environment.

C. History and Evolution of Camouflage Object Detection

The word “camouflage” was first coined by the French military during World War I. With the advent of new technology throughout the war like airplanes and long-range artillery, comes a pressing need to develop ways to conceal military assets from aerial and ground surveillance. To combat this predicament, French soldiers and artists began experimenting with contemporary ways to mislead their enemies by concealing equipment, vehicles, and even soldiers in plain sight by mimicking the colours and patterns of the surrounding environment. Soon, far and wide was the French word camoufler, which meant "to disguise" or "to conceal," spread and became widely adopted by other countries involved in the conflict. The growing importance of camouflage had led to the establishment of specialised units in those countries dedicated to the creation, advancement and implementation these concealment strategies. As time goes on, the word "camouflage" was no longer only used by the military as a tactic of concealment, but also a broader concept which refers to any method of blending into or disguising one's appearance within an environment, be it in nature, design, fashion, or technology, used to protect, hide, or obscure from detection.

Detection of camouflaged objects has evolved significantly over time. Visual inspection was the mainstay of early detection techniques, but new technologies that focused on physical attributes emerged as concealment tactics advanced. These technologies, such as infrared sensors [7] and thermal imaging, were first developed in the mid-20th century, particularly during and after World War II. These non-visual sensors [59] detect heat signatures, temperature differences, or variations in light and material properties, allowing camouflaged objects to be revealed. Infrared and thermal imaging systems, for example, became more advanced in the 1960s and 1970s. Later, in the late 20th and early 21st centuries, multispectral and hyperspectral sensors emerged. These sensors augmented detection capability by detecting wider range of electromagnetic wavelengths. These sensors augmented detection capability by detecting wider range of electromagnetic wavelengths. These technologies involve the use of heat and light properties, thus, making it possible to detect targets that are visually cloaked.

D. Approaches to Camouflage Detection

Traditional Human-Based Approaches

Traditional methods of camouflage detection have largely relied on human perception, leveraging the natural ability of trained observers to identify minute variations in a scene [8]. This is why trained observers are able to identify visual markers of slight discrepancies or changes in texture, colour or shape which indicates that an object is camouflaged. For example, even when the surroundings are very close visually with an object, trained observers are able to recognize the differences in patterns which lie out of the norm in the natural environment. Human perception also excels at detecting motion, shadows, reflections, and highlights, which are often telltale signs of camouflaged objects. Not to mention, humans can comprehend the broader context of the surroundings, easily detecting objects that do not seem to belong such as a soldier amidst trees or the tanks and cars in a desert. This contextual understanding, combined with cognitive abilities to interpret shapes and boundaries, allows people to identify camouflaged objects even when they are not immediately obvious.

However, while human perception has been a crucial part of traditional camouflage detection, it has its limitations. Detection accuracy can be affected by factors such as fatigue, attention span, and environmental conditions like lighting changes or visual clutter. Additionally, differing individuals may have varied perceptions of the same sight, which may result in inconsistent detection.

Physical Component-Based Approaches

Some technologies were created to try to compensate for human perception shortcomings where imagery camouflaging is concerned. Researchers have resorted to using technologies such as multispectral imaging, infrared sensors and LiDAR systems [7, 9]. Physical component-based techniques for detecting camouflaging have been used for quite some time now. These techniques make use of specialised hardware and technologies that use the physical characteristics of the surroundings to detect things that have been camouflaged. Their ability to analyse data across multiple wavelengths, depths, and even 3D structures that are beyond the capability of the human eye causes them to often be more effective than purely software-based or human-based methods. Such techniques typically require expensive and complex equipment but are essential for high-accuracy detection in military, security, and environmental applications.

Multispectral imaging was one such technology. It is defined as the technology which enables imaging systems to capture data across a wide range of wavelengths, from visible bands extending to non-visible bands to identify objects or individuals hiding through camouflage. [10] It aids in camouflage detection through multispectral photographic principles where more than one spectral band is used to measure the amount of light an object reflects or absorbs and produces an image of those which may not be visible in the normal case. This feature is particularly useful in detecting hidden targets that are visually obscured in the visible range. Additionally, multispectral systems often incorporate infrared sensors [11], which detect temperature variations that are invisible to the human eye. Such systems are able to deal with both visible and infrared technology thus offering a better picture of the constitution of the environment and enhancing the chances of detection of camouflaged objects under different circumstances.

In recent years, imaging technologies have made significant strides, particularly with the transition from multispectral to hyperspectral imaging. Hyperspectral imaging operates across hundreds of narrow spectral bands, capturing information about an object's reflectance across the electromagnetic spectrum, from ultraviolet to infrared wavelengths [12 – 14]. Every material has a specific spectral signature which is helpful in distinguishing it from its surroundings thereby being a game-changer in COD systems. While multispectral imaging captures data across a limited range of 3 to 10 spectral bands, hyperspectral imaging expands this by acquiring hundreds or even thousands of narrow spectral bands, allowing for a much more detailed and comprehensive analysis of the scene. With more details captured of the scene, this enhanced spectral resolution can offer explanations to certain levels of materials that wouldn't have otherwise been considered. Because they mostly rely on visible light or a limited range of spectral bands [12], traditional optical and multispectral techniques sometimes have trouble detecting disguised objects. However, the higher spectral resolution of hyperspectral imaging reveals invisible-to-standard-imaging differences in the of camouflaged objects' material properties, thereby improving detection.

The use of technologies like multispectral [15 - 18] and hyperspectral [19 - 22] imaging for camouflage detection offers several advantages, including enhanced detection capabilities through the analysis of multiple wavelengths of light, including those beyond the visible spectrum. For this reason, it becomes easy to find the camouflaged objects as it would be sufficient to perceive very slight changes in reflectance or temperature that the naked eye is not able to see. By contrast with other imaging methods, the resolution of the hyperspectral imaging is considerably higher since it can contain hundreds or even thousands of bands, making it easier to analyse the substance and its separation from other objects in the range of identical camouflaged regions. The drawback is that these systems are usually rather expensive and quite complex, so a lot of devices and time for training in effective visualization and extraction of the information are required. Additionally, the vast amounts of data generated by hyperspectral systems present challenges in processing and analysis, demanding substantial computational resources.

One of the less complex approaches are using cameras equipped with predator vision systems. Predators are known to be able to perceive camouflage more easily as they evolve to detect features such as patterns, movement, colour and depth to be able to capture prey. Researchers have modified cameras to emulate the vision of a predator and used it to detect objects such as the eggs of the nightjar and the nightjar itself [23, 57]. Cameras may also be equipped with infrared and thermal imaging.

E. Categorisation of COD Techniques

Human Vision

The most natural and the least carbon footprint inducing way for spotting camouflage is using the human's natural ability to detect objects and danger.

However, it is the method with the most limitations such as fatigue and inconsistency between different individuals.

Infrared detection.

Infrared happens to be an electromagnetic radiation (EMR), whereby its wavelengths shorter than microwaves but longer than that of visible light. As all objects produce infrared radiation, also known as heat, based on their temperature, infrared devices are able to detect, read and measure these waves. However, its ability is dependent on the object’s temperature.

Multispectral detection

This method uses specific wavelength across the electromagnetic spectrum to capture data of images. These wavelengths are detected using sensors or devices that are sensitive to these particular wavelengths. This allows for more data and information to be obtained compared to the human eye. Its early use was for military target identification and reconnaissance.

Hyperspectral detection

Mostly known as hyperspectral imaging, this method utilises information from across the electromagnetic spectrum. It collects and processes it to obtain the spectral data for each pixel of an image for object detection, material identification and more. The sensors used for this method typically collect information as a "images.” set. It is actually an advancement of multispectral imaging whereby hundreds of contiguous spectral bands are available, capturing a more detailed spectral data.

LIDAR detection

Mostly known as hyperspectral imaging, this method utilises information from across the electromagnetic spectrum. It collects and processes it to obtain the spectral data for each pixel of an image for object detection, material identification and more. The sensors used for this method typically collect information as a "images.” set. It is actually an advancement of multispectral imaging whereby hundreds of contiguous spectral bands are available, capturing a more detailed spectral data.

TABLE 1. Differences in approaches.

Approach	***Description***	***Strengths***	***Weaknesses***
Human Vision	Involves human perception using the eyes to visually identify camouflaged objects.	- Highly adaptable to complex, cluttered environments. - Capable of recognizing subtle visual cues and changes.	- Prone to fatigue, distractions, and bias. - Slower than automated systems. - Highly dependent on environmental conditions (e.g., lighting, weather).
LiDAR (Light Detection and Ranging)	Uses laser pulses to create 3D models of objects and surroundings by measuring distance.	- Works well in low-light and varied lighting conditions. - Excellent for creating 3D maps of environments.	- Can miss camouflaged objects that blend in with the background. - Limited by clear line of sight and weather conditions (e.g., rain, fog).
Infrared (IR) Imaging	Detects thermal radiation (heat) emitted by objects to identify temperature differences.	- Effective for detecting objects based on heat, useful in low-light or night conditions. - Works well for detecting living beings or warm objects.	- Can be fooled by temperature-matched camouflage or environmental factors (e.g., background heat sources). - Weather conditions (e.g., fog, rain) can degrade effectiveness
Multispectral Imaging	Captures data at multiple wavelengths across the electromagnetic spectrum, including visible and infrared.	- Can detect objects with unique spectral properties that differ from the environment. - Effective for vegetation and surface material detection.	- Requires precise calibration and setup for different environments. - Can be costly and complex to process large amounts of data.
Hyperspectral Imaging	Captures a much broader range of wavelengths than multispectral, offering detailed spectral data for each pixel.	- Highly accurate for detecting subtle material differences, even in camouflaged objects. - Can distinguish objects even when they blend in with the background.	- Expensive and requires significant computational power for data analysis. - Can be affected by environmental factors like cloud cover or atmospheric interference.

F. Comparison between the Human and Physical Component-Based Approach

TABLE 1. Comparison by factors

Factor	***Human-Based***	***Physical Components***
Detection Mechanism	Relies on visual perception and cognitive	Uses advanced technologies like LiDAR, infrared, multispectral, and

Factor	***Human-Based***	***Physical Components***
	interpretation of patterns.	hyperspectral imaging to detect objects.
Adaptability	Highly adaptable, capable of recognizing subtle patterns and making sense of complex environments.	Limited adaptability; dependent on the technology's capability
Detection Speed	Slower, since human attention and focus are required for thorough observation.	Faster and automated; can cover large areas in a short time without human involvement.
Technology Required	No specialized technology needed; relies on human sensory capabilities.	Requires specialized sensors such as LiDAR, infrared cameras, and multispectral or hyperspectral imaging.
Cost	Low cost	High cost due to the need for specialized equipment, software, and maintenance
Vulnerability to Countermeasures	Vulnerable to distraction, fatigue, and deliberate deception	Vulnerable to countermeasures like adaptive camouflage that can alter the object's thermal or spectral signature.
Flexibility in Detection Methods	Flexible; humans can adjust their detection approach based on visual cues and context.	Less flexible; detection is based on the specific capabilities of the technology
Dependency on Environmental Factors	Highly dependent on environmental conditions	Somewhat independent of visual conditions but may be affected by weather

G. Challenges in COD

Despite the technological there are always challenges in this field.

Anthropogenic changes refer to the changes which are the result of human activities. These changes impact a large span of the natural world and the biodiverse ecosystem as it disrupts or transforms the environment as we know it. Felt at at local, regional, and global scales, these changes affect the detection systems, as the environment may have dramatic shifts due to these changes [24 – 25] .

Since physical components are used in lieu of human observers for the majority of the time, electromagnetic interference comes as a cause of concern. Radio Frequency Interference (RFI) or electromagnetic fields from other devices or communication systems may interfere with the sensor's operation, especially infrared or hyperspectral [26, 58] sensors. Devices such as radar, communication towers, or other active sensors might produce signals as well which may interfere with the camouflaged objects' identification and detection.

Sensors such as multispectral and hyperspectral are also sensitive to signal jamming [27] methods. Detection systems might be susceptible to signal jamming or countermeasures, where deliberate interference is introduced to confuse or disrupt the sensor systems. For example, thermal camouflage can be used to block or disrupt thermal imaging systems. Humans may be unaffected by this, but the devices used to aid them in rapid detection may be affected by this.

Technological limitations are also a constant threat to the physical components. Each component has their own range and resolutions which they abide to. Anything that falls outside of their range are not detected, becoming a blind spot for these devices which limits their effectivity. Low-resolution systems might miss subtle camouflaged objects, especially in environments with high visual complexity. As an example, a camouflaged object in a dense forest or urban setting may need high-resolution infrared or thermal systems to be detected. Short detection ranges capabilities also render the components difficult to spot camouflaged objects from a long distance as well. Furthermore, physical components are also susceptible to environmental conditions such as variances in weather such as snow, fog, rain and wind and different seasons [28].

Other forms of camouflage are also a challenge as they are not being recorded subjectively. For example, dazzle camouflage [29 - 31], which confuses the depth perception, trajectory and speed of the animal, and Müllerian mimicry which may imitate the appearance of another animal or object. Although they can be detected to some capacity by the physical sensors, but they are still problematic in terms of accuracy. Furthermore, there are less studies as of now on this subject and how it impacts the detection of camouflage as a whole. Furthermore, there is an increase in development of high-fidelity camouflage, camouflage materials [32 - 33] that are increasingly sophisticated and realistic. These include technologies like adaptive camouflage or meta-materials designed to confuse optical and infrared sensors. Even as we speak, the military is constantly developing new techniques to fool existing COD techniques much like how prey and predator coevolve to be able to hide from and detect each other.

H. Recent Advances and Emerging Techniques

The interest in artificial intelligence (AI) has been present for a while. However, since the release of ChatGPT in 2018, AI has become increasingly pervasive in the research community, contributing to groundbreaking discoveries and innovations. Undoubtedly, large strides have been made using AI in the research of various fields, such as computer vision, robotics, and pattern recognition.

However, traditional AI techniques, particularly those in computer vision, still suffer from several limitations. These methods heavily relied on feature extraction and manual tuning, which often required extensive domain expertise and were prone to errors. Hence, they had difficulties learning things that were more general especially in dynamic and varied settings, which made them less effective in more complex activities like detecting camouflaged objects.

The advent of deep learning has caused researchers to attempt to integrate the new technology with human and physical component approaches. One such technique utilised human eye tracking, where one's eye movement is analysed and converted into data to understand the human point of view [34 - 35]. Then, it is fed to the deep learning system to study where individuals focus their gaze and for how long. A similar way may also be implemented with predator visions as they are more adept at spotting their camouflaged prey [36 – 37]. Another such technique but this time utilising physical components is the usage of hyperspectral images and deep learning. As hyperspectral images capture data across a broad spectrum of wavelengths. Detailed insights are obtained to identify materials, detect anomalies, and enhance environmental understanding for deep learning to use and learn. These and other similar new hybrid methods are paving the way for increasingly precise and adaptive systems in various applications, ranging from human-computer interaction [38] to environmental monitoring.

I. Applications

Security

Camouflage is frequently used by hostile forces to conceal troops, equipment, or military vehicles. COD is crucial for detecting camouflaged objects, such as tanks or soldiers hiding in forests, deserts, or urban environments. Military operations need this technology as distinguishing between friendly and enemy forces is vital for mission success [39]. Systems that possess COD technology can detect the heat signature or small changes in the surrounding landscape that are caused by a camouflaged object. Where there are landmines or unexploded ordinance as part of a defence, COD systems can assist in locating these explosives [40]. Mines may be integrated within the ground, but using physical components, may be able to find them by detecting heat contrasts and surface level changes.

There are many scenarios when border security forces come across concealed contraband like narcotic substances, weapons or any other illegal and dangerous material that may be hidden under a vehicle or on the ground. Smugglers and hostile entities commonly use sophisticated camouflage techniques to conceal these items, making detection difficult. COD greatly improves the surveillance at the borders by helping to detect masked items. The pre-existing technologies are already able to recognize patterns and anomalies indicative of hidden items, such as subtle differences in shape, colour, or texture that might not match the surrounding environment, flagging areas where contraband could be concealed. By integrating COD into border surveillance systems, security forces can significantly enhance their detection capabilities, allowing them to identify camouflaged threats in real-time, even in difficult or hostile environments. With COD, border security forces gain a critical advantage in preventing illicit activities, ensuring safety, and maintaining effective control over sensitive areas, offering increased efficiency and reliability in protecting national borders.

Environmental Monitoring and Conservation

Various animals and plants have evolved to have camouflage abilities that help them to evade predators. Most of them change colour or texture to blend with their environment, making it harder for prey or predators to spot them. In current modern conservation efforts, various techniques can be used to detect these animals in dense environments like forests, jungles, or underwater ecosystems where they are harder to spot using the naked eye. These technologies can rapidly identify camouflaged animals in real-time, enabling researchers to monitor wildlife populations more efficiently. These technologies not only assist in identifying animals with minimal contact but also supports behaviour studies and health assessments, improving conservation efforts by making it easier to track and study species that might otherwise be overlooked due to their camouflage.

FIGURE 4. Grasshopper mimicking lichen. [53]

FIGURE 4. Moth camouflaging. [53]

Furthermore, poachers conceal themselves or install hidden traps that are hard to spot in dense forest foliage or other wilderness areas. Poachers frequently use this tactic to become one with their surroundings to avoid the watchful eyes of park rangers and law enforcement. By deploying drones or cameras [42 - 46] equipped sensors with infrared, multispectral and hyperspectral capabilities, conservationists and wildlife authorities identify hidden threats, including human poachers or illegal hunting tools, such as traps and snares, with increased effectivity. These systems can analyse vast areas of forest or jungle in real-time to spot hidden poachers or animals trapped in snares which alert authorities immediately, allowing for quicker intervention to protect wildlife. This also allows better surveillance even in areas with fewer personnel as conservation work often has limited manpower. This significantly reduces the risks to park rangers and law enforcement officers, who would otherwise need to navigate treacherous terrains and potentially engage in dangerous, face-to-face confrontations with poachers, while providing more consistent, round-the-clock monitoring of protected areas.

Humanitarian Aid and Disaster Response

Since the terrorist attacks of September 11th, more robots and UAV [49] are being deployed for search-and-rescue operations as well as for damage assessment and aid in the reconstruction efforts in many places. These technologies are invaluable in reaching hard-to-reach places, giving real-time information, and helping rescue teams in life-saving missions. Their multi-faceted ability to quickly and effectively operate in different disaster environments has made them an essential part of modern disaster response strategies. But the effectiveness of those systems is greatly dependant on the capacity to perform in challenging and ever-changing environments where obstacles could be close at hand but obscured from sight.

These existing methods enables the machines to recognize and navigate environments with camouflaged objects especially in in disaster-stricken environments. Debris, rubble, and hidden hazards in the aftermath of a disaster often obstruct rescue efforts and human rescuers may struggle to locate victims or navigate through debris. Robots and UAVs equipped with these components will make it possible to identify obscured survivors, road signs, vehicles, or even buildings from a distance which might be hard to see without assistance. As a result, robots and UAVs will be capable of independently and quickly travelling inside of disaster zones making sure that every crucial target is reached. The procedure of searching then not only seeks to reduce the amount of time spent on searching but also enhances the effectiveness of rescue missions.

J. Future Directions

One of the pre-existing directions is the continuous enhancement of the technology of physical components. There is a constant strive for pushing the limits of technology to make it more accurate and reliable by enhancing the sensors and also improving the detection techniques. This direction will always be an existing factor as researchers will continuously push the boundaries of existing technologies.

Bioinspired techniques have also been emerging recently. Taking inspiration from pre-existing methods from nature, the technology of this field will shift towards this direction as we learn how animals detect camouflage prey and utilised mother nature's wisdom to improve existing techniques.

Humans already have a keep perception on camouflage objects, being able to detect snakes with high effectivity as humans are trained to detect danger [54]. Using this resource, human detection may be enhanced with the usage of augmented reality [55 - 56] to highlight potential threats in the environment. These augmented reality glasses may also provide data to the researchers to increase the knowledge of detecting camouflage objects.

III. Conclusion

In conclusion, the field of camouflage object detection (COD) is vital and developing, tackling the difficulties of detecting hidden items in intricate settings. From conventional techniques like physical component-based and human-based approaches to state-of-the-art technology like LIDAR detection, this overview emphasises the substantial developments in COD methodologies. Every strategy has distinct benefits and drawbacks, thus for best results, a balanced combination of approaches is required. Despite improvements in pinpointing concealed objects with technologies like hyperspectral imaging and infrared detection, accuracy, cost, and environmental adaptability remain challenging. Addressing these challenges requires continued research into hybrid models that combine multiple detection methods, along with advancements in artificial intelligence and real-time processing. With the continuation of development of COD technologies these methods will become more prevalent in security, surveillance, and even in disaster and ecological research, which will increase operational efficiency and detection capabilities in multitude of fields.

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Author contributions

Hi Chia Ling: Conceptualization, Data Curation, Methodology, Validation, Writing – Original Draft Preparation.

Kai Liang Lew: Proofreading, Project Administration, Writing – Review & Editing.

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Our research work follows The Committee of Publication Ethics (COPE) guideline. https://publicationethics.org.

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