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SENDING PICTURES OVER RADIO SYSTEMS OF THE TRAIL CAM IN BORDER SECURITY AND DIRECTING UAVS TO THE RIGHT AREAS

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ABSTRACT. In this study, a method is proposed for the trail cams to send data via narrow band communication systems in border security and counter-terrorism areas and to direct drones to the right areas. The success of UAVs lies in scanning the correct areas for observation or detection. UAVs should be fed with data to observe the correct regions, and the probability of detecting border security or terrorist elements should be increased. Instantaneous detection is performed by trail cam, which generally operate dependent on GSM. However, these devices cannot provide real-time data in border areas with low population density and no GSM service, particularly in counter-terrorism operations. In this study, the dependence of trail cam devices on GSM was eliminated, and data transfer over the radio system was established to enable real-time data flow in a wide field. After the trail cam device makes a detection, the data is sent via the APCO-25 JEMUS radio system with a capacity of 9.6 KB. The resolution of the detection image is reduced, allowing it to be displayed on a remote-control computer in less than one minute. As a result of the study, when an intelligent trail cam with object recognition capability is developed, the device can assess what the image might be in real-time. Obtaining real-time detection data from trail cams in border areas and counter-terrorism zones without GSM infrastructure can expedite the direction of UAVs to the correct regions for intervention by military units. Additionally, confirming that trail cam detects via narrowband communication systems in locations where units are temporarily stationed and without alpine terrain minimizes the surveillance vulnerability of UAVs unable to perform imaging due to adverse weather conditions. This also establishes a warning system against potential attacks by terrorist elements.

1. INTRODUCTION

Trail cams are actively used worldwide, especially to observe natural wildlife [1]. In our country, these devices are not only utilized for observing natural life but are also actively employed by the armed forces and law enforcement agencies for detection purposes in the context of border security and counter-terrorism [2]. Trail cams are

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equipped with sensors to detect motion or heat, and they feature specialized cameras [3]. These cameras are automatically triggered when they detect movement or a specific temperature difference [1, 2, 3]. Upon triggering, they capture photographs or videos. However, these devices have limitations such as weather and environmental factors, energy constraints, false triggers, and data processing challenges [4]. Furthermore, the current limitation of these devices lies in their reliance on GSM-based transmission for real-time visual communication. This reliance restricts their usage within the GSM coverage area or confines them to storing images in their own memory outside the coverage area [5]. The devices storing detection data on themselves leads to delayed learning by the intervention unit, hindering prompt action [1, 3, 4, 5, 6]. Additionally, when terrorists detect the devices or realize they are being tracked, they may booby-trap the devices with improvised explosive devices [7]. This poses a risk to personnel approaching the devices to retrieve data, resulting in injuries or fatalities [8].

To address these issues, new satellite-based camera trap devices are being developed to ensure continuous data transmission [7, 8]. Smart trail cams with satellite-based data transmission capability use on-device image processing algorithms for detection and provide wide coverage [7, 8, 9, 10,11]. However, the use of satellite transmission increases the cost of these devices, limiting their deployment to critical areas with a constrained number of devices [8]. Instant data transmission by trail cam is a crucial factor in minimizing casualties while combating terrorism, ensuring operational success, and responding promptly to incidents [7]. In areas without GSM infrastructure, narrowband communication systems are commonly used for communication [12, 13, 14]. Ensuring real-time visual transmission via these narrowband communication systems can address the challenges and minimize personnel vulnerabilities [13].

Narrowband communication systems generally refer to radio communication, providing communication within a limited bandwidth [14]. The coverage area of radio-based communication systems is significantly larger compared to GSM, especially when considering the eastern and southeastern borders of the Republic of Turkey and counter-terrorism operation zones, where the population density is low, leading to limited GSM infrastructure and coverage [15]. The existing coverage of narrowband (radio) systems in these areas is quite high, and it can be expanded in desired areas using mobile repeater centers [16]. Additionally, digital radio systems not only facilitate voice communication but also offer limited capabilities for location transmission and data transfer [15]. For instance, radios operating according to the Apco-25 standards provide a bandwidth of 9.6 kilobytes [15, 17].

In today's world, unmanned aerial vehicles (UAVs) used in border security operations are continually evolving to maximize the advantages of technology [18]. UAVs play an effective role in border areas, particularly due to the advantages they offer in reconnaissance and surveillance [19, 20]. The success of UAVs lies in scanning the correct areas for observation and detection [19]. UAVs need to be fed with data to observe the correct regions, and the probability of detecting border security or terrorist elements should be increased [21, 22].

When examining the advantages of UAVs in border security and counter-terrorism operations, reconnaissance and surveillance functions come to the forefront [23]. In situations where traditional surveillance methods fall short, UAVs can quickly scan a large area using high-resolution cameras and sensors to detect potential threats [24]. UAVs can maneuver rapidly and flexibly in border areas. Operating at a lower cost compared to traditional aircraft, UAVs can perform longer and more regular missions in border security operations, enabling more effective monitoring of border regions. UAVs can detect and analyze potential dangers in border areas [25]. Equipped with technological features such as thermal cameras, night vision systems, and radars, UAVs can identify smuggling, terrorist activities, and other potential threats in border areas, assisting in the implementation of preventive measures [26, 27]. The use of UAVs in border security operations can enhance personnel safety [24]. UAVs operating in dangerous or hard-to-reach areas do not jeopardize human safety [22, 23, 24]. Additionally, with a lower operational cost compared to traditional aircraft, UAVs allow for a more efficient utilization of border security budgets [24, 28]. To further enhance the effectiveness of UAVs by flying them in the correct areas, taking into consideration remote points in borders and settlements with natural vegetation, trail cam devices can serve as the "eyes" on the ground for UAVs. With advancements in imaging technologies, trail cam devices can play a critical role in providing data in border areas and directing UAVs to the right locations.

In this way, national border protection and illegal crossings will be prevented, the effectiveness of the fight against terrorists will increase, and effective use will be ensured by bringing together intelligent systems and controls in terms of national security. The aim of this study is to propose a method for the use of trail cams in wide-field applications in border security and counter-terrorism regions. This involves the real-time transmission of data through underutilized narrowband systems and the deployment of UAVs in the correct areas for control and detection.

2. Literature Review and Current Situation

To transmit image data over a radio system, it is necessary to first convert this image into digital data [29]. This process is typically carried out using a video compression algorithm. Commonly used algorithms include H.264, H.265 (HEVC), and MPEG-4 [30]. Radio systems are generally designed for voice communication [12-15, 31]. Therefore, it may be necessary to initially convert image data into audio data [31-

33]. This process involves carrying the image data over a voice communication channel and then converting it back into an image on the receiving end [14]. This often includes transforming the image data into a format compatible with voice communication protocols [31]. Once the image data has been transported over the voice communication channel, this audio data is sent to another center via a radio frequency [33]. This typically occurs in the form of a radio data packet. On the receiving end, the image data is received as audio data [14]. Subsequently, this audio data is processed to be transformed back into the original image data. This step involves using video compression algorithms utilized to convert audio data back into an image [34]. This process is quite complex, especially concerning the specialized protocols and algorithms used in radio communication systems. Additionally, issues of privacy and security are crucial in such communication, hence specialized encryption methods ensuring secure communication are often employed.

2.1. **Steps for Data Transmission Over Radio.**

a. Matrix Transformation of the Image;

Let's consider a matrix representing the image as I. Each element $I_{i,j}$ represents a pixel of the image. This matrix typically has three channels according to a color space (e.g., RGB).

I: Original image matrix (dimensions m×n)

$I_{i,j}$: Element of the original image matrix (dimensions m×n)

b. Video Compression;

If a video compression algorithm is used, it usually employs a transformation matrix C. This transformation matrix compresses the original image matrix into a compressed format.

C: Compression matrix (usually a transformation matrix)

′I′: Compressed image matrix

$$I' = C x I \quad (1)$$

c. Conversion to Audio Data;

The compressed image matrix is then transmitted over a voice communication channel. This communication typically uses a protocol designed for audio data.

f: Function that converts the compressed image matrix to audio data

S: Audio data

$$S = f(I') \quad (2)$$

d. Transmission via Radio: Audio data is transmitted to another center over a specific frequency by the radio system. This process typically occurs using a radio communication protocol.

T: Transmission matrix (transmission over the radio)

$$T(S) \quad (3)$$

e. Processing at the Receiver Radio: After receiving the audio data at the receiver side, this audio data is first transformed back into the original image matrix. This process can be mathematically expressed as follows:

g: Function that transforms audio data to the original image matrix

″I″: Original image matrix obtained at the receiver side

$$I''=g(T(S)) \tag{4}$$

Communication devices conforming to the APCO-25 standard can be connected to tablets or computers via connectors for the purpose of data transmission when desired [32, 33]. Data transfer is facilitated through data relays located in repeater centers. Additionally, the location data of these radio devices can be viewed from the central control software through the GPS module [32]. The data transmission duration from the radio device is dependent on the size of the transmitted data. Therefore, reducing the size of the sent image will decrease the transmission time. The process of reducing image size is typically achieved using data compression algorithms. The mathematical formulation of these algorithms varies depending on the specific details of the algorithms employed and the compression method used. The JPEG compression algorithm, for instance, typically compresses the original image through a process known as Discrete Cosine Transform (DCT) and quantization. These processes can be mathematically expressed as follows.

2.2. **Discrete Cosine Transform (DCT) Process F(u,v).** DCT coefficients in the frequency domain of the original image f(x,y): Pixel values in the time domain of the original image M and N: Dimensions of the image,

$$F(\boldsymbol{u},\boldsymbol{v}) = \mathbf{C}(\mathbf{u})\mathbf{C}(\mathbf{v})\sum_{\boldsymbol{y}=\mathbf{0}}^{\boldsymbol{N}-\mathbf{1}} \mathbf{x} \sum_{\boldsymbol{y}=\mathbf{0}}^{\boldsymbol{N}-\mathbf{1}} \mathbf{f}(\mathbf{x},\mathbf{y})\mathbf{cos}\left[\frac{(\mathbf{2}\boldsymbol{x}+\mathbf{1})\boldsymbol{u}\boldsymbol{\pi}}{\mathbf{2}\boldsymbol{M}}\right]\mathbf{cos}\left[\frac{(\mathbf{2}\boldsymbol{y}+\mathbf{1})\boldsymbol{u}\boldsymbol{\pi}}{\mathbf{2}\boldsymbol{N}}\right] \tag{5}$$

c. Quantization Process:

Q(u,v): Quantization table

Fq(u,v): Quantized DCT coefficients

$$\mathbf{Fq}(\mathbf{u},\mathbf{v}) = \frac{\boldsymbol{F}(\boldsymbol{u},\boldsymbol{v})}{\boldsymbol{Q}(\boldsymbol{u},\boldsymbol{v})} \tag{6}$$

These steps involve obtaining the Discrete Cosine Transform (DCT) coefficients of the original image in the frequency domain, followed by the quantization process to represent these coefficients with lower precision [34]. The JPEG algorithm compresses these quantized coefficients further through additional steps such as zigzag scanning and Huffman coding [34, 35]. This formulation only exemplifies the JPEG compression algorithm. For other compression algorithms, different mathematical expressions may arise depending on the methods and techniques employed [34, 35].

3. Material and Method

In the conducted study, two radio devices, one receiver and one transmitter, compliant with the Apco-25 standard, one trail camera, connection cables, and one tablet were utilized. The transmitter and the trail camera were interconnected and placed in a forested area. The location data of the trail camera was obtained through the radio device. The acquired location of the trail camera was marked on a map within the central control software. When the trail camera captured an image through triggering, it stored the image locally and transmitted information about the detection via a short message to the receiver radio device. The central control software installed on the tablet connected to the receiver radio device issued a notification of the detection, including the trail camera's identification number and the date and time of the event. The user personnel could view the notification and, at their discretion, initiate the process of locking the reduced-resolution image data to be transmitted by the transmitter radio device. This allowed the image data to be visible on the control computer.

4. The Experimental Section and Discussion

Unmanned Aerial Vehicles (UAVs), also known as drones, provide the capability to rapidly diagnose potential threats in border regions and operational zones [19, 23, 24]. To ensure effective visual monitoring of violations and terrorist elements and to enable swift intervention within the legal framework, UAVs must operate in the correct areas. Instant visual transmission by trail cameras in the field will offer significant advantages to armed forces and law enforcement in maintaining dominance and detecting irregular migration movements by directing UAVs to the right areas. Trail camera, equipped with high-resolution cameras and sensitive sensors, have the capacity to obtain detailed images in border regions. These devices can operate effectively in both day and night conditions, providing valuable data in various weather conditions.

While these devices are capable of obtaining high-resolution images or videos, for the military and law enforcement, the information that there is a violation and detection in the captured image is more crucial in the initial stage for prompt intervention. This is because responding to a violation or a terrorist element requires a rapid and efficient process that operates against time. Therefore, promptly reporting the detection to the control center is of vital importance.

The ability of trail cameras to transmit data via radio is often encountered as a technology used for remote control and data collection. While these devices are typically used for observation and monitoring in nature, their remote control and real-time data transfer are facilitated through radio transmission.

For camera traps to perform data transmission via radio systems, the device must establish a connection with a control unit in the field or a main station that enables remote access for the user. Additionally, data security during radio transmission is another aspect that needs to be considered for such devices.

During radio transmission, the security of data is of paramount importance. End-to-end encryption is a critical element for data security. By employing encryption during data transmission, protection against threats such as unauthorized access and data manipulation is ensured.

The radio transmission of trail cameras provides users with the ability for remote control and monitoring in areas without GSM infrastructure. This allows users located remotely from the device's position to view live footage, adjust camera settings, and control the device remotely.

The use of trail cameras must comply with legal regulations and ethical standards. Special attention should be paid to matters such as personal privacy, protection of private spaces, and conservation of natural habitats.

4.1. **Advantages of Radio Transmission of Trail Cameras.** Trail Cameras offer various advantages in security applications when utilizing radio transmission.

a. Area Monitoring and Motion Detection: Trail Cameras can detect potential threats by continuously monitoring a specific area through their motion detection capabilities. This feature is crucial, especially in areas such as border security, counter-terrorism, facility security, and wildlife conservation. Combined with motion detection, security personnel can be instantly informed, enabling swift intervention.

b. Image and Video Recording: Trail Cameras typically feature integrated cameras capable of high-resolution image and video recording. These recordings can be used to document, substantiate, and analyze security incidents. Additionally, these images can be used to assess the effectiveness of measures taken during an event.

c. Resilience to Weather and Environmental Conditions: Camera traps are generally weather-resistant and can be adapted to various environments with suitable casings. This adaptability allows effective use in applications such as counter-terrorism and border control.

d. Covert and Remote Positioning: Trail Cameras used in security applications are often concealed or camouflaged, allowing them to go unnoticed while detecting and recording potential threats. The remote controllability of trail cameras enables security personnel to manage devices in areas with difficult access or potential risks.

e. Rapid Intervention and Interactive Control: The real-time information provided by camera traps enables quick intervention and interactive control. Combined with motion detection, security personnel can promptly dispatch airborne elements or intervention personnel to the area. If necessary, devices can be remotely controlled, providing security teams with the ability to respond quickly and effectively.

f. Energy Efficiency: One of the significant advantages of camera traps transmitting notifications via radio is the use of low-power radio frequency (RF) transmission. This contributes to energy efficiency, allowing for prolonged device usage. RF transmission typically occurs in dedicated frequency bands, reducing interference with other wireless devices. Additionally, the ability of smart camera traps to wake up and perform object or person recognition upon motion detection minimizes unnecessary data transmission and energy consumption. Designing suitable energy sources such as solar panels or battery packs for these devices can further enhance their long-term field use. Energy-efficient sensors and electronic components also contribute to energy savings.

4.2. **Disadvantages of Radio Transmission of Trail Cameras.** Trail Cameras have the following disadvantages.

a. Cost Factors and Limitations of Widespread Use The cost of high-quality camera traps and radio transmission systems may limit the widespread adoption of this technology. Establishing a network spread across large areas for observing wildlife, conducting research, or for security purposes can impose a substantial financial burden. However, considering the geography of Turkey, military units in border areas, especially in operations related to internal security and counter-terrorism, have existing radio communication infrastructure along the border lines.

b. Sensor Sensitivity and Environmental Challenges Accurate operation of camera traps requires sensitive sensors. However, environmental conditions, weather, and natural factors can affect sensor performance. Factors such as dense vegetation, precipitation, and temperature fluctuations can lead to sensors providing incorrect positive or negative responses, reducing the reliability of the obtained data.

c. Connectivity Issues Radio transmission can be problematic in remote areas or areas with dense vegetation. This can result in devices being unable to reliably transmit data to the control center, preventing users from effectively managing the device. Particularly in remote and isolated areas, issues like blockage or attenuation of radio signals can challenge the reliability of these systems.

d. Energy Management and Battery Life Considering that camera traps are often used in natural environments, energy sources become a critical factor. While energy sources such as solar panels or battery packs are used, these sources have limited capacities. Especially in situations requiring prolonged observation and data collection, special attention must be given to energy management and battery life.

Following the detection process, a notification of the detection was sent via short message through the radio data transmission channel. The receiver radio device, connected to the tablet, displayed an alert of the detection using the control software. After receiving the detection alert, a request for image data was sent to the transmitter radio device via short message. The process of compressing and reducing the resolution of the image data was initiated on the camera trap device, and the transmission of the compressed image data to the receiver radio device was started by the transmitter radio device. The entire process ensured that the reduced-resolution image data, approximately 400 to 500 megabytes in size, was visible in the control software within a time frame of approximately 45-60 seconds. The process is illustrated in Figure 1.

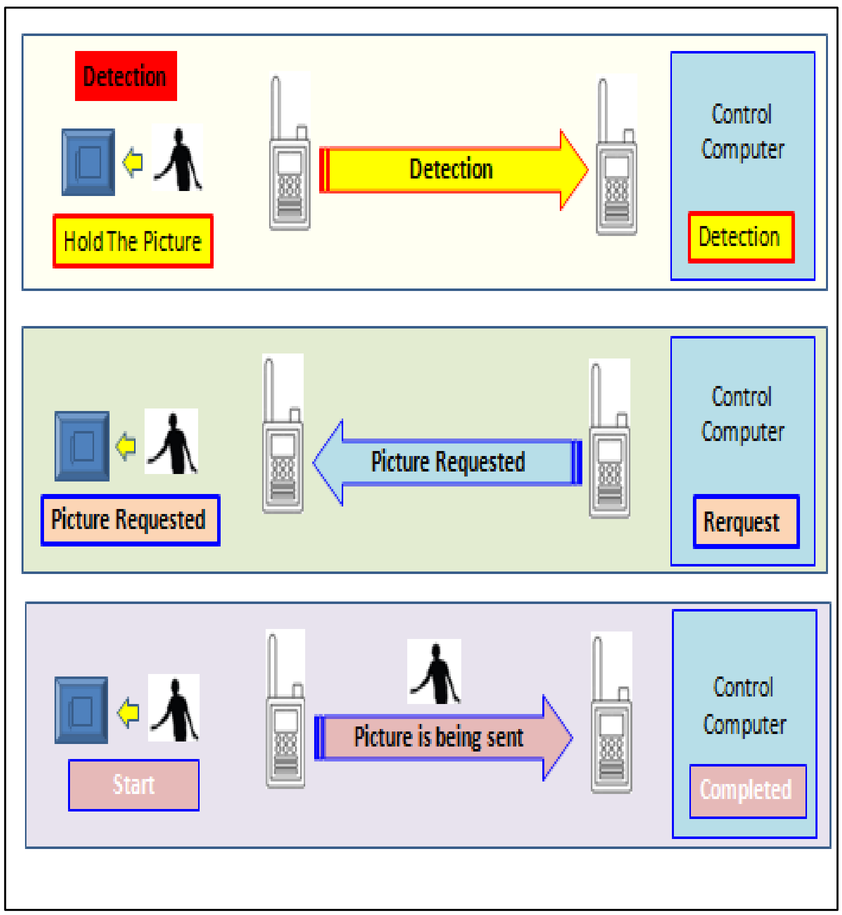

FIGURE 1. Post-detection flowchart.

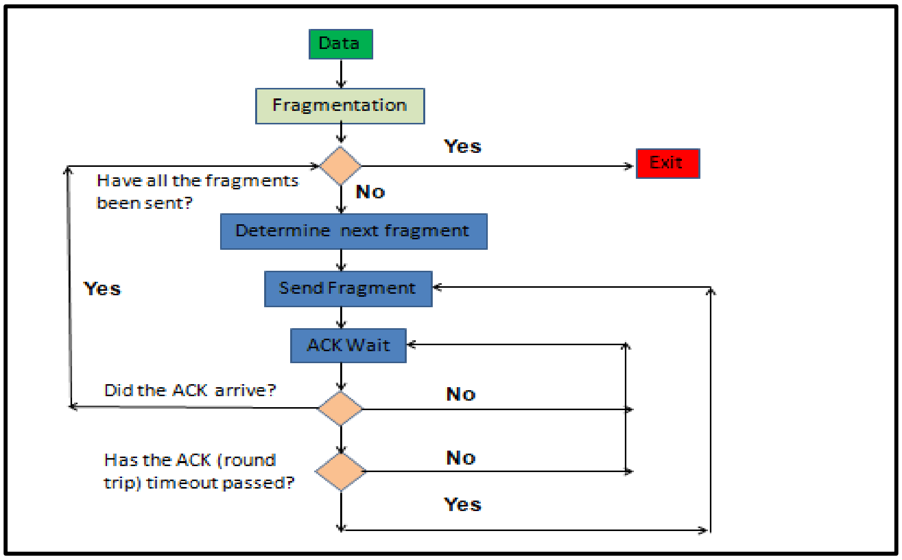

FIGURE 2. Data transmitting radio (ACK= Acknowledgment).

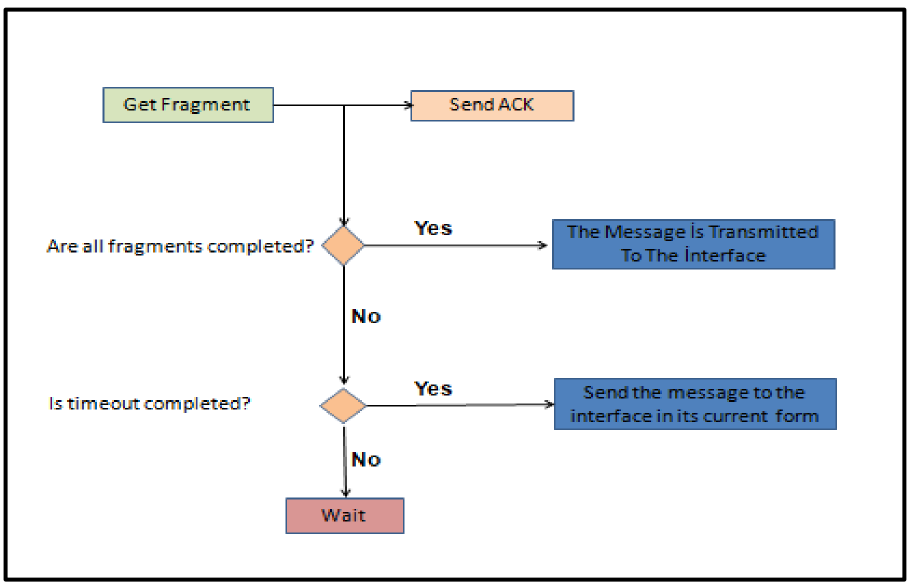

FIGURE 3. Data receiving radio (ACK = Acknowledgment).

Conducted in the experimental study, the process carried out by the camera trap device following the detection is depicted in Figure 2. The operation performed by the receiver radio device is illustrated in Figure 3.

The operation of trail cam systems, particularly in border regions, via radio systems for data transmission, is crucial for ensuring the perimeter security of stationary units. Attacks on these stationary elements typically occur in conditions where visibility is limited, and unmanned aerial vehicle (UAV) elements cannot conduct surveillance due to adverse weather conditions, such as cloud cover. In this context, it can be utilized as a security measure for the unit and as an early warning system with advanced surveillance capabilities. Similarly, in densely forested areas, UAV surveillance can pose challenges.

The image obtained by the camera trap device connected to the radio system in a forested area is depicted in Figure 4.

FIGURE 4. The image captured by the camera trap is transmitted through the radio device.

After the conducted study, the radio system with a data transmission capacity of 9.6 kbytes was utilized to transmit image data. By reducing the resolution of the image, it was ensured that the image data, ranging between 350-500 kbytes, could be captured from the desired camera trap device in less than approximately 1 minute when needed.

5. CONCLUSION

The study results indicate that with the development of an intelligent trail camera equipped with on-site object recognition capabilities, the device responsible for recognition can initially assess what the image might contain in real-time. This allows the radio device to provide preliminary information to the user regarding the detection through the radio device. Based on the user's preliminary assessment, the detection image can be viewed within approximately one minute. This aspect has been demonstrated in the established test setup. Consequently, limitations such as GSM coverage restrictions or the disadvantage of holding images that cannot be obtained instantly on the trail camera can be overcome. This enables the detection of irregular migration movements, border crossings, and the identification of terrorist elements in areas where trail cameras cannot be used due to their limitations. As a result, UAVs can conduct reconnaissance and surveillance in the right areas. Additionally, the technology can be utilized for the safety and advanced surveillance of locations where UAVs are temporarily unable to provide surveillance due to adverse weather conditions, offering significant advantages to the Armed Forces and law enforcement.

While the transmission advantages of trail cameras through radio signals are evident, disadvantages such as compliance with legal regulations and concerns about privacy should also be taken into consideration. To effectively and responsibly use this technology, users must exercise caution and adhere to local regulations. The integration of trail cameras with UAVs has the potential to enhance border security operations, making them more efficient, rapid, and secure. This technological integration is seen as a crucial step in increasing national security and monitoring border areas more effectively. Therefore, trail cameras should be used via GSM-based communication in areas with GSM infrastructure and through radio or satellite-based communication in critical and essential areas where GSM infrastructure is not available for real-time visual data transmission and extensive field use.

Declaration of Competing Interests The authors declare no conflict of interest.

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