Güvenlik Bilimleri Dergisi / Journal of Security Sciences

Jandarma ve Sahil Güvenlik Akademisi
Güvenlik Bilimleri Enstitüsü
Güvenlik Bilimleri Dergisi, Mayıs 2024,Cilt:13, Sayı:1, 63-84
doi:10.28956/gbd.1454962

Gendarmerie and Coast Guard Academy
Institute of Security Sciences
Journal of Security Sciences, May 2024,Volume:13, Issue:1, 63-84
doi:10.28956/gbd.1454962

Makale Türü ve Başlığı / Article Type and Title
Araştırma/ Research Article
An Ai-Based Surveillance System Proposal for the Second Line of Defense Against Irregular Migration, Smuggling, and Terrorism: Gendarmerie Assessment
Düzensiz Göç, Kaçakçılık ve Teröre Karşı İkinci Savunma Hattında Yapay Zekâ Destekli Gözetleme Sistemi Önerisi: Jandarma Değerlendirmesi

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Bilgilendirme / Acknowledgement:
-Yazarlar aşağıdaki bilgilendirmeleri yapmaktadırlar:
-Makalemizde etik kurulu izni ve/veya yasal/özel izin alınmasını gerektiren bir durum yoktur.
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Bu makale Turnitin tarafından kontrol edilmiştir.
This article was checked by Turnitin.

Makale Geliş Tarihi / First Received : 18.03.2024
Makale Kabul Tarihi / Accepted : 14.05.2024

Atıf Bilgisi / Citation:
Güven M., (2024). An Ai-Based Surveillance System Proposal for the Second Line of Defense Against Irregular Migration, Smuggling, and Terrorism: Gendarmerie Assessment, *Güvenlik Bilimleri Dergisi, 13(1), ss 63-84. doi:10.28956/gbd.1454962*

AN AI-BASED SURVEILLANCE SYSTEM PROPOSAL FOR THE SECOND LINE OF DEFENSE AGAINST IRREGULAR MIGRATION, SMUGGLING, AND TERRORISM: GENDARMERIE ASSESSMENT

Absract

Despite the physical and technological measures in place along the border protected by border forces, a significant number of irregular migrants are being apprehended by gendarmerie (Jandarma) elements in the area designated as the second line of defense. This situation poses a crucial responsibility for the Jandarma in the context of preventing irregular migration movements, curbing smuggling activities, and combating terrorism. Therefore, it is proposed that artificial intelligence-supported technological discovery and surveillance measures be implemented in the Jandarma responsibility area behind the border. It is believed that these technological measures could be beneficial in preventing irregular migration movements, restricting smuggling activities, and enhancing effectiveness in the fight against terrorism. The implementation of these measures could contribute to public safety by increasing security and maintaining order. Within the scope of this study, a thermal camera network system powered by solar energy, featuring wireless communication capabilities, and equipped with artificial intelligence analysis, is described. Additionally, the technical architectural features of the system, installation requirements, and details of the artificial intelligence algorithms to be utilized within the system, along with their capabilities and potential algorithm specifics, are explained. The implementation of the proposed system is anticipated to enhance reconnaissance and surveillance capabilities.

Keywords: *Artificial İntelligence, Machine Learning, Gendarmerie, Law Enforcement, Irregular Migration, Crime Prevention.*

DÜZENSİZ GÖÇ, KAÇAKÇILIK VE TERÖRE KARŞI İKİNCİ SAVUNMA HATTINDA YAPAY ZEKÂ DESTEKLİ GÖZETLEME SİSTEMİ ÖNERİSİ: JANDARMA DEĞERLENDİRMESİ

Öz

Sınır birliklerince korunmakta olan hudut hattındaki fiziksel ve teknolojik tedbirlere rağmen ikinci hat olarak tasvir edilen Jandarma sorumluluk alanında, Jandarma unsurlarınca çok sayıda düzensiz göçmen yakalanmaktadır. Bu durum; düzensiz göç hareketleri, kaçakçılık ve benzeri suçların önlenmesi ile terörle mücadele bağlamında Jandarma için önemli bir sorumluluk oluşturmaktadır. Bu nedenle hudut hattının gerisinde Jandarma sorumluluk sahasında yapay zekâ destekli teknolojik keşif ve gözetleme tedbirlerinin alınması önerilmektedir. Söz konusu teknolojik önlemlerin, düzensiz göç hareketlerini engelleme, kaçakçılık faaliyetlerini sınırlandırma ve terörle mücadelede etkinlik sağlama konusunda faydalı olabileceği düşünülmektedir. Adı geçen tedbirlerin uygulanması, emniyet ve asayişi artırarak toplum güvenliğine de katkı sağlayabilir. Bu çalışma kapsamında; güneş enerjisi ile çalışan, kablosuz iletişim özellikleri taşıyan ve yapay zekâ analiz yeteneğine sahip termal kamera ağı sistemi tarif edilmektedir. Ayrıca söz konusu sisteminin teknik mimari özellikleri, kurulum gereksinimleri ile sistem kapsamında kullanılacak yapay zekâ algoritmalarının kabiliyetleri ve muhtemel algoritmaların detayları açıklanmaktadır. Önerilen sistemin uygulanması ile keşif ve gözetleme kabiliyetlerinin artıracağı değerlendirilmektedir.

Anahtar Kelimeler: *Yapay Zekâ, Makine Öğrenmesi, Jandarma, Kolluk Kuvvetleri, Düzensiz Göç, Suç Engelleme.*

INTRODUCTION

As of today, world has seen the largest number of refugees and forcibly displayed population worldwide in the human history. Moreover, the trends are dramatically increasing over the course of the last decade. For example, in the year 2022, the global population forcibly displaced due to persecution, conflict, violence, human rights violations, and events severely disrupting public order experienced a significant increase of 21 percent, reaching an estimated 108.4 million by the year-end (United Nations High Commissioner for Refugees' statistics). This accounts for more than 1 in 74 individuals worldwide being forcibly displaced, with nearly 90 percent of them situated in low- and middle-income countries. The concluding total at the end of the year reflects a surge of 19 million individuals compared to the conclusion of the preceding year, surpassing the populations of Ecuador, the Netherlands, or Somalia. This escalation marks the most substantial annual increase on record in the United Nations High Commissioner for Refugees' (UNHCR) statistics on forced displacement as seen in Figure-1.

The notable rise is attributed to the unprecedented numbers of refugees, asylum-seekers, and individuals requiring international protection compelled to flee during 2022, constituting over half of the overall increase. Furthermore, during the 2023, forced displacement has continued to escalate, with UNHCR estimating that the global figure likely surpasses 110 million people as of the first quarter of 2024.

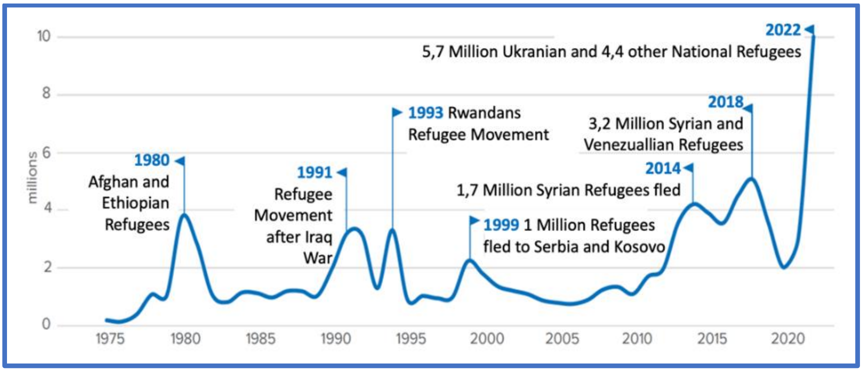

Figure-1. Refugees, Asylum-Seekers, and other People in Need of International Protection Displaced since 1975.

The invasion of Ukraine and the takeover of the Taliban in Afghanistan precipitated the displacement of millions of individuals, leading to an upward trajectory in the Figure-1 for refugees, asylum-seekers, and forcibly displaced persons.

Specifically, Türkiye harbors one of the most substantial refugee populations worldwide (Global trends forced displacement). Moreover, its neighboring countries Syria, Iran, and Iraq have considerable number of potential refugees. Türkiye serves not only as a destination but also as a transit country (T.C. İçişleri Bakanlığı Göç İdaresi Başkanlığı). The influx of refugees predominantly utilizes the eastern borders of the nation as the primary entry point, underscoring the critical significance of border security in this context. From this perspective, we turn our attention to the topography of Van city, a region boasting the largest border with Iran. Situated along the historic Silk Road, this area has become a pivotal route for various illicit activities. The Van city terrain exemplifies a critical junction for illegal movements, where not only individuals but also smuggled goods traverse, underscoring the historical significance of this region in facilitating clandestine operations.

Currently, securing the borders is the responsibility of the Turkish Armed Forces. Despite the deployment of physical and technological measures along the border, a substantial number of irregular migrants continue to be apprehended within the jurisdiction designated as the second line of defense by the Gendarmerie. This situation underscores the urgent need for innovative and effective solutions to address the complex issues associated with irregular migration movements, smuggling activities, and counter-terrorism efforts.

Considering these challenges, this study proposes the implementation of a cutting-edge system to enhance reconnaissance and surveillance capabilities within the Gendarmerie's responsibility area beyond the border. Diverging from conventional drone-based approaches, our solution involves a wirelessly connected thermal camera network, fortified with advanced artificial intelligence algorithms for the analysis of thermal camera footages. This departure from traditional methods is crucial in adapting to the evolving landscape of border security and is expected to provide a more nuanced and effective approach in curbing irregular migration, restricting smuggling activities, and bolstering counter-terrorism initiatives. In the ensuing sections, we will delve into the technical intricacies of this proposed system, exploring its architectural features, installation requirements, and the capabilities of the integrated artificial intelligence algorithms.

1. RELATED WORKS

Artificial intelligence (AI) has garnered significant attention within academic circles and across various industries. This heightened interest can be attributed largely to a fascination with attaining military and political dominance, as well as a motivation to exert influence over individuals and their actions. AI has been utilized in border security, with AI systems being deployed along physical borders to monitor and control the movements of unauthorized non-citizens, as well as to enhance overall border security measures (Sanja Milivojevic, 2022). Employing AI to analyze vast datasets at border crossings can lead to complete visibility and heightened automation in border control, ultimately achieving an ideal of intelligent and secure borders at a relatively low expense (Heyman, 2008). The resultant AI-generated comprehensive depiction of border transformed from the basic elements of traditional border control infrastructure such as border equipment, surveillance devices, and border personnel.

In a study conducted by Manish K. et al., an AI-powered method that facilitates the sharing of information from diverse sources is proposed as a solution for border security. This includes the use of various sensors strategically placed around the perimeter of a specified area to detect any unauthorized disturbance, intrusion. Upon detecting such activity, the system automatically activates drone surveillance and relays the location of the disturbance to both the drone and nearby soldiers. This approach enables efficient tracking of the disturbance, aiding in apprehending any potential threats. Additionally, cameras installed on the drone assist in tracking and monitoring targets as necessary. Processing big data is an important research topic for mitigating the border security breaches and illegal actions such as smuggling. For example, Artificial Neural Networks and Logistic Regression are employed in this study conducted by Wen, Chih-Hao et al., for classification and prediction purposes. The study develops models tailored to vessels of varying tonnage and operational purposes, offering law enforcement clearer criteria for judgment. Results indicate that using Artificial Neural Networks for smuggling fishing vessels can achieve an average precision of 76.49%, while Logistic Regression can achieve 61.58% accuracy, both of which significantly surpass the efficiency of human inspection. This highlights the potential of information technology to enhance the probability of apprehending smuggling vessels and leveraging database information to combat smuggling crimes effectively.

In the literature, there are also ethical concerns of the AI-driven borders. AI-driven borders are fundamentally nonhumanitarian and legally questionable, as they prevent unauthorized migrants from reaching safe havens and expose them to danger, and in some instances, fatal outcomes at border crossings. What distinguishes AI from other technological advancements in border control, such as CCTV, ground-level radars, or thermal camera imaging, is its promise of complete visibility at borders and increased automation. This promise, shaped by the context in which it emerges and the challenges it addresses, is increasingly influenced by ideology (O'Grady, 2021).

The utilization of thermal imaging technology has become increasingly prevalent in border and coastal security initiatives worldwide. The integration of advanced thermal imaging cameras with innovative system architectures built on IP networks and video analysis technology has led to significant advancements in system performance and flexibility for users. For example, in a study conducted by Dumpert Dwight T., an overview of these cutting-edge technologies and the benefits they bring to the user community in enhancing border and coastal security measures.

In another study conducted by Gutin Mikhail, AI-driven solutions for border security were explored, focusing on the development of the Automatic Panoramic Thermal Integrated Sensor (APTIS) which combines high-resolution panoramic optics with thermal imaging and intelligent video processing for automated target detection, location, and tracking. This system promises enhanced surveillance capabilities, reduced personnel workload, and improved situational awareness in defense and offensive operations, making it a significant advancement in border security technology.

In this study conducted by Dawoud ALshukri, border security and AI are utilized to address the challenges commonly faced in border areas, including violence, intrusion, and difficult geographical conditions. The proposed system employs thermal imaging cameras connected to the control center via IP addresses on a local network. Software captures video for intrusion detection, while a motor-controlled spotlight with infrared and laser capabilities provides illumination as needed. Moreover, the system integrates sound sensors for specific sound detection and motion sensors for identifying suspicious movements. Upon detection, the system can activate a buzzer and electric current through the fence for added protection. The use of Internet of Things facilitates efficient control across large borders.

We are shifting our focus to detecting weapons in camera footage because distinguishing illegal activities such as smuggling or irregular migration from terrorist activities in this area is of utmost importance. So, in this part of literature review, we present works that are focused on smart surveillance systems detecting anomalies such as weapon existence.

In a study conducted by Sanam Narejo et al., YOLOv3 is retrained via images consisting of several weapons in the images. The image dataset utilized was gathered from the Google by searching directly for keywords related to weapons. The images obtained from the Google were then categorized into various subfolders such as gun, rifle, and so on. Transfer learning, defined as inheriting knowledge from a pre-trained model, was employed. YOLOv3, which was initially trained on the ImageNet dataset with multiple output classes, was further trained using images sourced from the Google. The objective was to enable YOLOv3 to detect guns, rifles, and other relevant objects within the images.

In this study conducted by Lei Pang et al., a real-time detection method is proposed via using the YOLOv3 algorithm to identify concealed metallic weapons on the human body in passive millimeter wave (PMMW) imagery. PMMW technology operates within the electromagnetic spectrum, specifically in the frequency range of 30 to 300 gigahertz. It is known for its ability to detect thermal radiation emitted by objects. The experimental data utilized in this study consisted of a collection of images acquired by a PMMW real-time imager developed at Beihang University, China. According to the results, VGG16, YOLOv3-53 demonstrated superior performance with a mean average precision of 95% on a GPU-1080Ti system.

In another study conducted by Warsi et al., significant contributions were made to automatic handgun detection in visual surveillance by integrating the YOLOv3 algorithm with Faster Region-Based CNN. Their approach involved differentiating false negatives and false positives, incorporating real-time images with the ImageNet dataset, and training the model using the YOLOv3 algorithm. They conducted a comparative study between Faster RCNN and YOLOv3 using four different videos. The results revealed that YOLOv3 exhibited faster processing speeds in real-time environments compared to Faster RCNN.

2. PROPOSED SYSTEM DESIGN

The proposed system can be categorized into two main components: the physical infrastructure and the software infrastructure. The physical components include essential infrastructure elements such as fences, site security camera systems, solar panels, receivers, antennas, surveillance towers, thermal cameras, etc. Conversely, the software component encompasses various artificial intelligence software and servers situated at the command-and-control center.

2.1. Physical Infrastructure

Main element of the system is the security tower site. This site is represented in Figure-2, and sites respectively have a; 10-meter-long tower, thermal cameras attached to the top of the tower, receiver, and antenna units for transferring thermal camera and footage, solar panels.

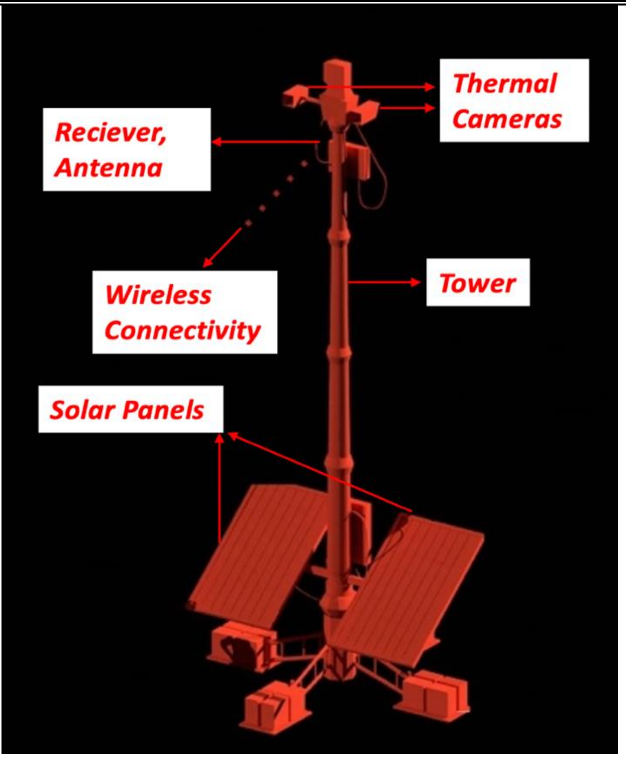

Figure-2. Representation of the Site Elements.

Enhancing site security against external threats and ensuring the operational continuity of the site can be achieved by reinforcing solar power through electric grid connection, where available, and securing the perimeter with fencing. Autonomous surveillance sites are intended to locate remote areas, so securing them and keep them up and running every time is an important aspect. These towers are interconnected and linked to a regional monitoring center, which, in our case study, is either a Gendarmerie Station or District Gendarmerie Command.

2.1.1. Connectivity and Network Topology

Wireless networks have recently emerged as innovative, cost-efficient, state-of-the-art alternatives to conventional technologies in various application domains. These networks are used to transfer data especially in security cameras and surveillance applications (Akhilesh Shrestha and Liudong Xing, 2007). Network topology affects the communication in various ways such as communication reliability, energy efficiency, data latency, etc. Some of the well know network topologies are star, mesh, tree, and clustered hierarchal architecture as seen in Figure-3.

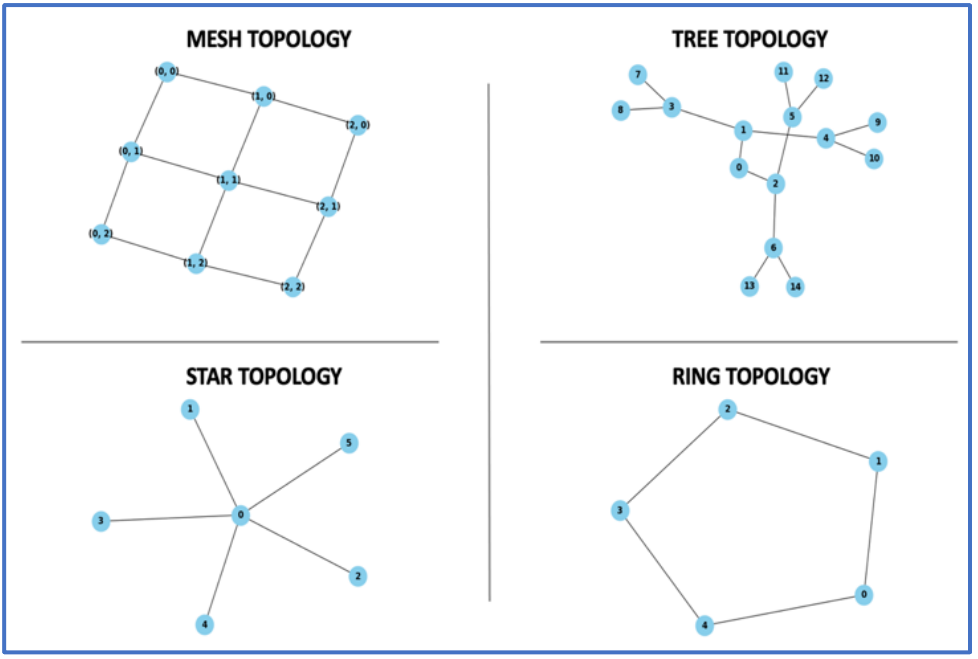

Figure-3. Some of well-known network topologies.

The star topology is the simplest form, with a central hub located in the middle. This central hub can be either a node or a gateway device. In this topology, if the central node goes down, all connectivity is lost. Mesh networks are interconnected with multiple points, enhancing the resilience and reliability of this type of network. Another commonly used topology is the tree network. In tree network, neighboring nodes have connections with each other. The reliability of such networks depends on the number of multiple connections that exist.

One of the prevalent challenges in wireless networks of this nature is the presence of Single Points of Failure (SPF) nodes. Figure-4 illustrates an SPF failure scenario. As depicted in the figure, tree topologies are considerably more susceptible to SPF. For instance, if node 3 malfunctions, connected nodes 7 and

8 are also affected. In contrast, mesh topology is resilient to SPF as there is always an alternative communication pathway available.

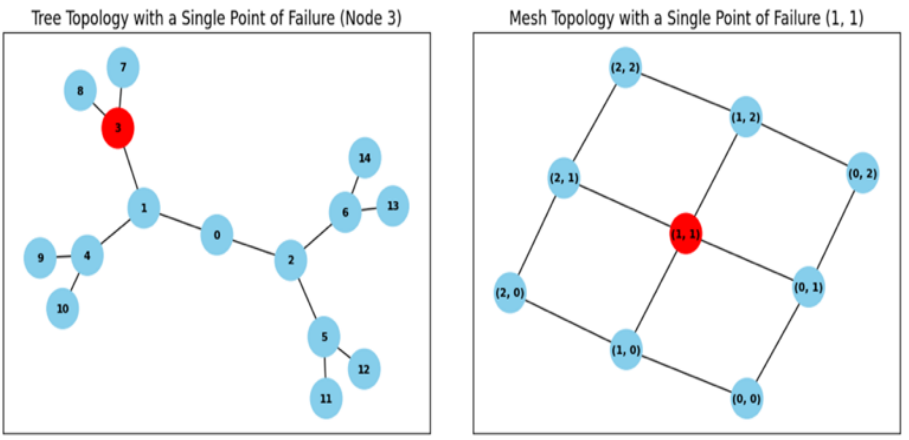

Figure-4. SPF in Tree and Mesh topology.

2.1.2 Connectivity and Network Topology of the Gendarmerie Case

As stated before, we hypothetically located our proposed system and tower on the Van City Terrain. In our proposed methodology, we have autonomous towers on the field, and these towers are connected to neighboring towers to make a substation connection and footage of the thermal cameras from towers are transferred to either a Gendarmerie Station or District Gendarmerie Command that have fiber connection with command-and-control center. The proposed topology that is presented on Figure-5 is an amalgamation of tree and mesh network. The connections between towers work in two ways, ensuring a mesh topology. Consequently, the footage from Tower 1 is transferred to District 2 through both Tower 2 and Tower 3. Additionally, Tower 1's footage is transmitted to District 1. This topology ensures highly reliable and resilient communication.

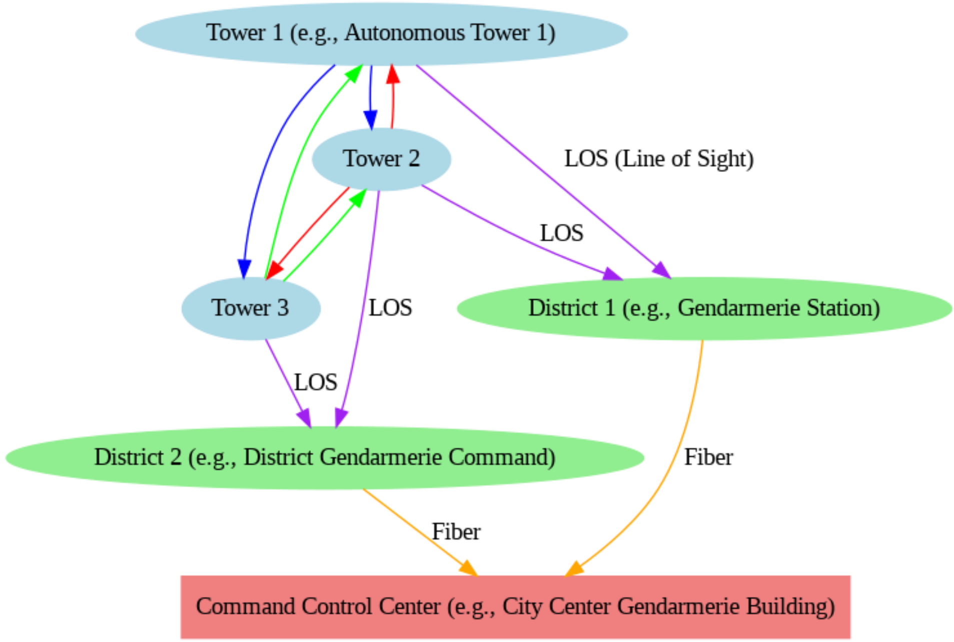

Figure-5: Network topology of the proposed system in our specific Gendarmerie case.

Towers are interconnected with multiple neighboring towers and the gendarmerie station. In this figure, green zones represent the areas visible to the thermal cameras mounted on top of 10-meter-long towers within a 5 kilometers radius. Conversely, red areas indicate blind zones outside the cameras' line of sight. All towers have the capability to both receive and transfer all the data they possess and receive. Each tower is assigned a specific IP address, and the UDP transfer protocol is employed to mitigate data latency and efficiently utilize the bandwidth.

To cover the entire border line between Van province and Iran, a total of 36 autonomous towers, with 9 regional monitoring hubs, each of which is either a gendarmerie station or a district gendarmerie command can be located. From these regional monitoring hubs, all camera footage is transmitted to the command-and-control center located at the City Center Gendarmerie Building. In our tower constellation, we aim to converge all possible routes, roads, and paths that could be used for illegal human and goods trafficking. Moreover, in this tower constellation, the potential downtime of any tower does not interrupt the continuous operation of the overall system. The constellation of the towers is presented in Figure-6.

Figure-6: Constellation of the proposed system on Van City terrain.

2.2. Software Components

Within the scope of our proposed system, thermal camera footages undergo processing through various artificial intelligence algorithms, serving two primary functions. The first task involves detecting moving objects in the video. Upon detecting a moving object, the second algorithm is activated to perform the classification task. This task involves determining whether the object is a human or an animal. Such automation is crucial, as human observers might miss changes in the videos due to factors like exhaustion or lack of attention.

2.2.1. Moving Object Detection

The identification of physical object motion within a specified spatial domain, known as moving object detection, has garnered considerable attention in recent years owing to its diverse array of practical applications. These applications encompass video surveillance, analysis of human motion, navigation for autonomous robots, event detection, anomaly identification, video conferencing, traffic analysis, and security protocols.

Moving object detection refers to the process of delineating dynamic objects of interest in relation to their surrounding area or region within a provided sequence of video frames (Jaya S. Kulchandani, 2015). The fundamental stage for classifying and tracking moving objects involves the identification of the moving targets. The primary objective of the moving object detection and tracking process is to detect the foreground moving targets (Ayush Baral, 2019). There are several methods for detecting moving objects in a video, respectively: background subtraction, frame differencing, temporal differencing, and optical flow.

Within the literature, certain studies have focused on performing moving object detection using thermal cameras (Lenac Kuruno, 2015). These investigations involve conducting various experiments on thermal images, where the differentiation in pixel values is utilized to isolate and identify moving humans within the image.

2.2.2. Object Classification

As part of our proposed system, after detecting moving objects in thermal images, the subsequent task involves classifying these detected objects to determine whether they are human beings or animals.

Specifically, in our proposed system, we are looking for human existence. This is a very active field and have been largely studied over security camera footages, unmanned air vehicle (UAV) footages, etc. (Hazar Mliki, 2019). Human detection through deep learning methods remains a prominent research area that continues to garner attention and has not been fully explored yet. These methods rely on automatic feature extraction, primarily utilizing convolutional neural networks within the same framework, as demonstrated by AlDahoul et al (N. AlDahoul, 2018). Another important technique is using pretrained models in human detection. For example, in a study, the AlexNet model and substituted the SoftMax layer with a hybrid classifier combining Support Vector Machines and K-Nearest Neighbors to tailor the model is used (A. B. Sargano et al. 2017).

3. ARTIFICIAL INTELLIGENCE PART OF THE SOFTWARE: YOLO

YOLO (You Only Look Once) has emerged as a pivotal real-time object detection system with applications in robotics, driverless cars, and video monitoring. A comprehensive overview of YOLO's evolution, detailing the innovations and contributions in each iteration, ranging from the original YOLO to subsequent versions such as YOLOv8, YOLO-NAS, and YOLO with transformers are presented in the literature (Juan Terven, 2023). Our discussion begins with an explanation of standard metrics and post-processing techniques before delving into the significant changes in network architecture and training methodologies introduced in each model. We then distill the key insights learned from YOLO's development and offer a perspective on its future, emphasizing potential research avenues to enhance real-time object detection systems.

3.1. Working Mechanism of the YOLO and Experimental Results

YOLOv1 revolutionized object detection by simultaneously predicting bounding boxes and class probabilities across an S x S grid. Each bounding box prediction includes confidence (C) for object presence, box coordinates, and dimensions. The output tensor is S x S x (B x 5 + C), optionally refined by non-maximum suppression to eliminate redundant detections YOLOv1 revolutionized object detection by simultaneously predicting bounding boxes and class probabilities across an S x S grid.

In this section, our attention is directed towards YOLOv3, which serves as the foundational framework for the most recent and expedient iteration of the algorithm. YOLOv3, a cutting-edge object detection model, boasts a robust architecture with multiple outputs tailored for detecting diverse classes of objects. This model is equipped with three output layers, each responsible for predicting different bounding boxes, object probabilities, and class probabilities within a given image. These outputs collectively facilitate the identification and localization of various objects simultaneously. Training YOLOv3 to detect a new class of objects involves a process known as transfer learning. This approach leverages the pre-existing knowledge and learned features from the model's training on a large dataset, such as ImageNet. To adapt YOLOv3 for detecting a new class, one typically follows these steps:

- Data Collection: Gather a dataset containing images that showcase the new class of objects you want the model to detect. These images should be labeled with bounding boxes indicating the location and class of each object.

- Model Initialization: Initialize YOLOv3 with its pre-trained weights, obtained from training on a generic dataset like ImageNet. This step ensures that the model already possesses foundational knowledge about object detection and feature extraction.

- Fine-Tuning: Perform fine-tuning or retraining of the model using the new dataset. During this process, the model adjusts its internal parameters and learns to recognize the specific characteristics and features associated with the new class of objects.

By following these steps, YOLOv3 can be trained to detect a new class of objects, such as weapons or abnormal walking patterns. Adopting this capability to AI software will be very useful in our proposed AI-based thermal camera surveillance system and should be considered a future work.

YOLOv3 is also recognized as Darknet-53, this version comprises 53 convolutional layers, as illustrated in Figure-7, showcasing its architectural layout.

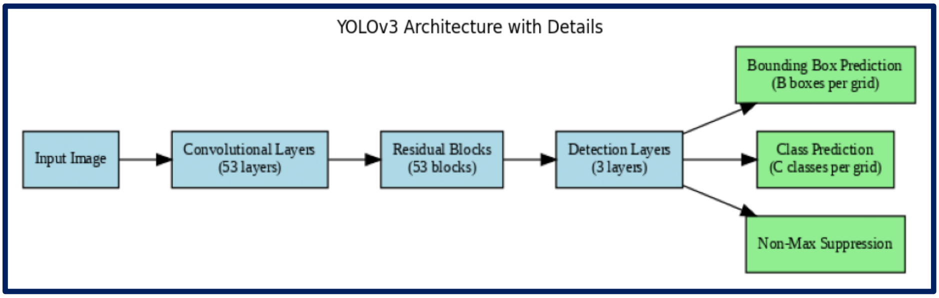

Figure-7. YOLO v3 architecture.

To demonstrate the artificial intelligence component of our proposed system, we conducted experiments using YOLOv3 on a variety of images, encompassing both standard RGB images and thermal camera images. The following lines of code were employed to apply YOLOv3 for object detection and classification within the images.

Algorithm: Target detection and classification via YOLO.

Input: Image **I**, model weights **W**, model Confidence **C**, and Threshold **T**

Output: Detected objects and their bounding boxes in Image I

1. Load YOLO model with weights W and configuration C
2. Preprocess Image I for YOLO
3. Pass preprocessed image through YOLO model
4. Get output predictions from YOLO model
5. Initialize an empty list for detected objects and bounding boxes
6. For each prediction in output predictions:
7. Extract class ID, bounding box coordinates from prediction
8. If confidence score > T: Calculate absolute coordinates of bounding box relative to image size
9. Add detected object class and bounding box to the list
10. Return list of detected objects and bounding boxes

From the pseudocode provided above, a simple code in Google's Colab environment is realized as seen in the Figure-8 below.

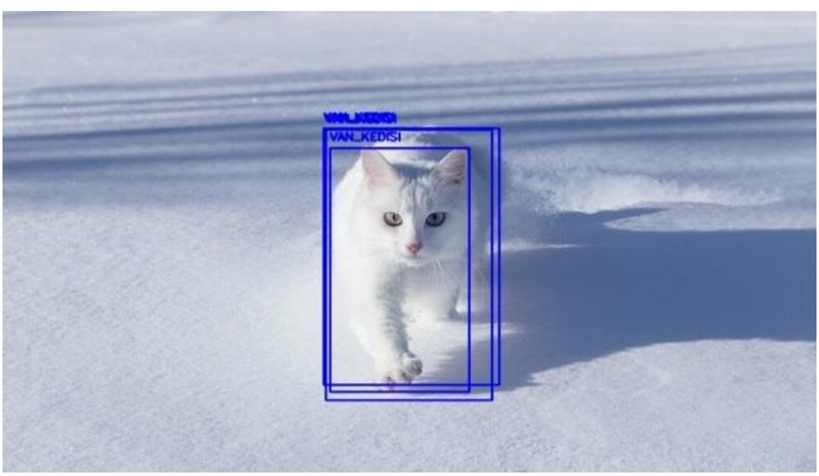

Figure-8. YOLOv3 implementation and resulting image.

To broaden the scope of our experiments, thermal images were incorporated. We utilized pre-trained weights for YOLOv3 and retained the default class labels without modifications. Based on these default class labels, our model segmented the thermal images into categories such as human presence, vehicle presence, etc. The outcomes of this segmentation are illustrated in Figure-9.

Figure-9. Thermal images experimented via YOLO v3.

The series of images presented showcases various scenarios: **starting from left to right and top to bottom**, the first image depicts two pedestrians walking at 10 meters, followed by a thermal camera's view capturing a pedestrian 20 meters away from an armored vehicle in the second image. Moving on, the third image shows an armored vehicle captured by a thermal camera at 30 meters, while the fourth image features a pedestrian located 15 meters away. The fifth image displays a thermal perspective of an armored vehicle, and the final image captures two pedestrians positioned 100 meters away, with additional sheep visible in the lower-left corner of the scene. Notably, all subjects falling under our defined class labels, including humans and vehicles, were successfully detected, and classified within these images.

4. CONCLUSION

In conclusion, the persistent challenges faced along border regions necessitate innovative solutions to enhance security and surveillance measures. Despite existing physical and technological defenses, irregular migration, smuggling activities, and potential security threats persist, particularly in areas designated as secondary defense lines. The utilization of artificial intelligence-supported technologies, such as the YOLO v3 algorithm tested in this study, presents a promising avenue for bolstering border security and surveillance capabilities. By leveraging thermal imaging technology powered by sustainable energy sources and integrated with wireless communication and AI analysis capabilities, the proposed system offers an efficient and effective means of detecting and monitoring human and vehicle movements in border areas. The implementation of such advanced technological solutions not only strengthens efforts to combat irregular migration and smuggling but also contributes significantly to counter-terrorism initiatives. Ultimately, these measures aim to safeguard public safety, maintain order, and enhance the overall effectiveness of border security operations.

DATA AVAILABILITY STATEMENT: The images and the codes used in this paper can be accessed here https://github.com/mesuttguven (accessed on 17 March 2024).

ACKNOWLEDGEMENTS

The author expresses their gratitude to Major General Aykut TANRIVERDI and Brigadier General Adem ŞEN for their valuable insights into the system design process and their visionary approach to leveraging state-of-art technology for addressing challenges related to irregular migration, smuggling, and terrorism. Additionally, special thanks are extended to Major İnanç MARIM, the commander of Van Commando Battalion (Central), for providing thermal images from various surveillance, and to Lieutenant Mursel AZAR for his insightful work in pinpointing the tower locations and overall tower constellation.

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