UNDERSTANDING GEOSPATIAL CHALLENGES & TECHNOLOGIES: TOWARDS A HYBRID SYSTEM FOR BORDER MONITORING

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ABSTRACT: *International border-security operations are diverse and include tasks to facilitate the legitimate movement of goods, thwart crime, maintain safety around borders and safeguard natural resources. All of these operations are vital and enduring; however, three operations are currently of exceptional concern to the European Union countries: counterterrorism, illegal drug control, and illegal migration. Many systems were developed to assist border authorities with more effective surveillance and reliable decision-making support. Such systems vary in the terms of the used technology, accuracy, types of events that can be detected and monitoring continuity. This paper investigates the technical capabilities of existing and proposed surveillance systems used for international border monitoring applications. It describes the effectiveness of these systems along with the technological infrastructure required for their implementation. Particular attention has been given to identifying the strengths and weaknesses of these systems and their ability to meet current and future challenges. Analysing current solutions shows that there is no single technology that performs best in all situations and there is a need for integrating multiple technologies to achieve a high level of security. This study is of interest to monitoring technology experts, security analysts and border guard authorities responsible for establishing and implementing border-security systems and trying to understand how to develop measures for the effectiveness of homeland security programs.*

Keywords: Border surveillance, Illegal crossing, Wireless Sensor Networks, Hybrid Systems.

1. INTRODUCTION

Continuous monitoring of international borders has become a necessity in recent years due to the steady increase in organised crime, terrorist threats, and smuggling activities [1-3]. Any gaps or interruption in monitoring may cause severe damage to the security of a given country. However, continuous border surveillance is a challenging and expensive task, and its processes and systems require a high degree of accuracy.

Recently, the central Mediterranean route has become a serious concern to the European Union (EU) state members [4]. This route refers to the North Africa flow towards the EU through the Mediterranean Sea. Smugglers use old fishing boats with no sufficient sailing equipment, fuel, and navigation to cross immigrants to Italy or Malta [5]. In 2008 alone, 40000 emigrants attempted the illegal crossing to the EU through this route. This has almost stopped in 2009 after Italian-Libyan agreement. After the eruption of civil unrest in 2011 in Libya and Tunisia, the number has increased rapidly reaching more than 64000 immigrants. The immigrants' number is increasing every year since and in 2014, 170 thousand migrants arrived in Italy [4].

The Eastern EU border is another area of concern to the EU [6]. The most recent statistics show an increase in the number of threats caused by illegal activity in this location [6, 7]. The illegal activities involved include illegal crossing, smuggling of tobacco, vehicles, petroleum products and drugs. In one incident only, four million cigarettes were smuggled over the Russian-Finnish border [7]. According to a recent FRONTEX report [6], there is a 24% increase in 2014 in the number of reported illegal border crossings, compared with 2013. These crossings were conducted between checkpoints. Latest figures show that 45% of detected land crossings of the Eastern Mediterranean side of the EU are at the Bulgarian-Turkish border.

The EU's Ukrainian border is one of several key 'trouble spots' allowing illegal crossing to the EU, and, according to the FRONTEX report [7], it is "the central transit and origin of irregular migration at the common borders". In addition, Ukraine is the main transit area for Afghanistani, Eritrean, and Somalian illegal migrants. The EU's Ukrainian border is made up of about 24,000 square kilometres of land. This border is geographically unique and extremely complex. A section located between Poland and Ukraine is 535 kilometres long. Figure 1 shows the EU's Ukrainian border on a map.

Figure 1 The EU's border with Ukraine

The Bug River is located in the northern part of the border and is surrounded by plains, but there are mountains and forests found in the South. In this location, traditionally, border monitoring is conducted through manual means, using physical checkpoints or tasking entire military units with monitoring certain sections of the border.

These two examples illustrate the scale and complexity of securing international borders. The geographical length of the borders combined with the topographical challenging nature, e.g., coastal plains, high mountains, dunes, and large deserts, make it infeasible to deploy border guards personal without monitoring gaps. Moreover, the cost of such mission would be excessively high. This lead to increasing interest in developing intelligent border monitoring systems to help countries protect their citizens. The best form of border surveillance involves minimal human intervention [8]. Systems that currently exist for border monitoring range from the simple fence and wall systems to very complex surveillance devices. Intelligent border monitoring systems are desirable because they increase operational efficiency, but, simultaneously, reduce costs [9]. Modern monitoring systems face considerable variable challenges and demands. Such demands include large, busy, and complex landscapes. There are also demands for real-time acquisition and interpretation of evolving events, and instantaneous identification of potentially critical situations in all weathers and lighting conditions.

This paper discusses existing border surveillance systems, their limitations and the current challenges facing border surveillance systems in light of emerging threats. The severe limitations of current systems motivate the development of a new monitoring system that is low in cost, suitable for covering large geographical areas and combine the advantages of existing systems by efficiently integrating them to provide a complete system. We present the argument that Wireless Sensor Network (WSNs) are particularly well-suited to dealing with modern day border breaches. WSNs are a candidate solution to modern and evolving challenges in the field of border surveillance. They are low-cost, autonomous, devices that can be spatially distributed in harsh environments to monitor physical conditions and respond to pertinent changes accordingly.

The rest of the paper is organised as follows: Section 2 reviews the strengths and weaknesses of exiting border-monitoring systems. Section 3 discusses the limitation of the current systems. Section 4 presents the design challenges and requirements of a new monitoring system. Section 5 presents the need for a new border monitoring system. Section 6 concludes the paper and highlights future research avenues.

2. Existing Border Surveillance Systems

This section presents a review of the most recent and prominent commercial as well as experimental international borders monitoring systems. This review limited to land border-monitoring systems, where most threats originate. It is important to note that there is a general lack of resources with detailed information about these systems due to their sensitive military nature. Thus, we present the relevant systems using the best available resources. Nevertheless, despite the lack of literature, we acknowledge and discuss the general problems pertaining to these systems when possible.

Image processing-based surveillance

The first class of border surveillance systems is the image processing-based surveillance. In image processing-based systems, borders are monitored from the sky using various technologies including satellites, Unmanned Aerial Vehicle (UAV) and monitoring balloons. In general, these systems operate by comparing the current view with a pre-recorded one; any changes are reported to the end users.

One of the popular satellite-based systems is called Change Detection Phenomena-based Monitoring (CDPM) [10]. CDPM involves capturing and recording images of and information about a particular place from two different locations. This is commonly done using a satellite that monitors activity in a place constantly and records any difference that has occurred in the monitored environment during a fixed time-slot. This model was used by the EU along with the Ukrainian border for preventing any illegal movement across the border. The working principle of this system is that images of an area must be captured at different intervals. For accuracy, the calibrations of instruments, and the resolution of imaging devices must be kept constant when taking images across two different periods. Image processing, voice signal threshold, and modulation activities must be performed to refine the images and voices that are recorded [11]. This system was designed with the demands of monitoring different geographical areas in mind. One challenge for this system concerns differentiating between changes that may occur due to natural reasons and changes that might occur due to humans crossing the border. This system is also susceptible to natural conditions, such as cloud cover and other weather changes, which can also affect the monitoring effectiveness in terms of miss-rate or false alarms.

Another satellite-based system used to monitor the European external borders is EUROSUR [12]. This system is engaged in surveillance across the Schengen borders using satellite data to track vessels and smugglers movement. The purpose of EUROSUR is to reduce the movement of illegal immigrants across borders by providing the common technical framework required to facilitate cooperation and round-the-clock communication between different member state authorities. The key motivation underpinning the EUROSUR project was to support member states in their efforts to reduce the number of illegal immigrants in Europe. EUROSUR has the same limitations as CDPM plus limitations related to the complexity of technical operations and maintaining coordination.

With the aim of improving decision-making and diplomatic approaches to solving immigration matters emerging from the European maritime border, DOLPHIN was designed [13]. DOLPHIN prevents or reduces the death toll of illegal human trafficking through rescue operations. DOLPHIN is governed by EUROSUR to specifically control any type of immigration activity along the EU maritime borers [14]. Dolphin inherits all the limitations of EUROSUR. Being a sea-based border system limits its use to maritime borders only. In addition, the system was designed only for EU maritime use [13], which hinders international collaboration.

To overcome the problems with satellite surveillance, a CCTV-based border monitoring system was developed in 2001 by EVPU Defence [15]. EVPU Defence is known for a number of projects, such as deploying pans or tilts, which are intended to provide customers with optimal short-range surveillance. EVPU designed both fixed and mobile products. This allows rapid deployment of resources to respond to emerging threats. As a surveillance system, EVPU is intended to achieve the objectives of effective stationary and mobile multi-sensory systems by acting on targets quickly and flexible. Using new SAMBA technology, SAMBA is a polarization-difference digital camera based on a fast (up to 10 KHz) polarization analysis, increases video quality and protects large areas from unwanted intrusion by trespassers and illegal crossers. This system is, unfortunately, tied to the Czech Republic, and, as such, is not open to other nations. In addition, the newly introduced SAMBA technology may be erroneous to some extent [15]. The main drawback of CCTV-based systems, as for other systems presented here, is the intensive human involvement required in operating the system.

Predefined hybrid systems

The second class of the border monitoring systems is the hybrid systems, which integrate multiple technologies. The goal of such systems is to achieve effective monitoring under various conditions, e.g., dark, cloudy, and no line of sight. Technologies used include mobile/fixed CCTV, radar, fibre-optic cables, sensors, satellites, etc. Combining multiple technologies increases the deployment and operational cost of the monitoring systems. Moreover, we observe that most of these systems suffer from the limitations of rigid design, i.e., they require major modifications to include new technology. Moreover, technology vendors put little effort in providing interfaces to allow integration with other systems. This is mainly due to the sensitive military nature of the products as well as commercial reasons.

Helios is a Distributed Acoustic Sensor (DAS) system created by a British company called Fotech Solutions [16]. Helios utilises CCTV, fibre-optic cables, lasers and sensors for border monitoring. Originally, it was designed and proposed for surveillance across Southern Arizona's borders specifically, and in other parts of America as well. Helios is still in development, yet, it has a number of features that distinguish it from other existing border surveillance systems including it minimises the hassle of wires; it has a considerably larger scale than other systems, and it offers greater accuracy (up to 1 meter) of an intruder using GPS. However, interfacing with mobile communication and the internet for remote monitoring is a major flaw as most of the borders are out of internet coverage.

The WESTMINSTER surveillance system [17] was designed to assist in the provision of high-quality services pertaining to fencing and other physical mechanisms for preventing border encroachment. The system features bespoke surveillance and border-cross detection (for land, sea, and air). WESTMINSTER offers control along borders made up of diverse terrains, which is ideal for curbing illegal immigration and human trafficking [17]. The system uses solar power to illuminate remote borders, and makes use of RADAR, UAVs, drones, SONAR, and small craft detection systems to detect illegal crossings [18]. WESTMINISTER is by far the most mature and comprehensive solution in the market. However, it is designed to function only with a set of predefined vendors and technologies, which can lead to a lack of cooperation with other systems. This also could mean that clients may be paying for a technology that is not relevant to their environment. This leads to unjustifiable additional installation costs above those of lesser systems, and human involvement is essential to operate the system, which has implications in terms of training and salaries.

Flexible hybrid systems

Many defence organisations have released the drawbacks of the predefined hybrid systems and introduced a new class of systems, which we refer to here as the flexible hybrid systems. These systems offer a generic platform that allows the integration of compatible technologies and hardware to provide a continuous monitoring that suits the application requirements.

BorderSense [19] makes use of various existing technologies such as sensors, UAV and monitoring towers. One of the key advantages of BorderSense is that it requires minimal involvement from humans – ideal for cost-cutting, and for surveillance of inhospitable terrain. The technologies embedded in the entire system constitute multimedia and sensing devices, under-the-surface sensing devices, and mobile surveillance nodes. The system provides beyond-the-line-of-sight detection, i.e., even if a target is covered by some kind of material, it can still be properly detected, allowing for tracing and eventual interception of the target. Visibility is considered a point of weakness in many border systems. For this reason, the underground sensing capability of BorderSense is one of its key selling points. Although it incorporates existing technologies, the architecture of BorderSense is slightly different to existing monitoring techniques that are available. A variety of heterogeneous nodes are operationalised in this form of the surveillance system, which increases range as well as accuracy, and reduces the degree of false alarms at the same time. Another major advantage of this system is the compatibility with aerial surveillance systems. Since BorderSense is a hybrid system, it has the capacity to easily accept new systems/technologies, which makes it one of the most capable of modern systems [19]. However, BorderSense installation is complex and it was not been thoroughly test in a real-world environment.

Cassidian [20] Border Solution was developed by Airbus Defence and Space as a highly-integrated border surveillance system. It deploys an artificial intelligence feature that is capable of gathering, aggregating and evaluating data from numerous sources [21]. The system uses encrypted communication subsystems to provide a high level of security. Its design assumes a set of predefined fixed and mobile command centres, which provide users with decision-making tools, helping them to conduct the required operations effectively [20]. However, such capabilities require an expensive infrastructure.

A significant example of hybrid border monitoring systems is the one proposed by FLIR [22]. FLIR, a company specialised in thermal imagining, offers solutions for land border protection, maritime monitoring, and airport security. Their systems combine a variety of sensors, such as thermal cameras, radars, and a host of other sensors, in order to achieve the best available degree of detection and surveillance. FLIR operationalises reliable and cost-effective equipment, claiming low false-alarm rates and a low life-cycle, which allows it to survive in all weather conditions. The main advantage of this system is that it limits the number of false alarms experienced in most border security systems [23]. FILIR equipment is very expensive and require a huge capital investment, which makes it unpopular solution. Moreover, the system requires continuous human operation [22].

Thales, another world leader in the defence industry, proposed a hybrid border surveillance system [24] to improve basic border management and control. The system offers an impressive and high-quality service using standalone equipment, such as sensors. Thales offers services to customise its product for logistic support purposes. The product comes with a set of training tools and services to support its adoption [24]. Thales design philosophy was to ensure that present security levels are evaluated and appropriate preparations for the future are made. They tailored current operations to securely adapt to present IT hardware and software. Additionally, the system comes with a complete and modern turnkey Integrated Border Management [25]. Nevertheless, Thale's border monitoring system has some weaknesses, these include: assuming partnership and collaboration between neighbouring countries; and thicker and denser areas of terrain may be impenetrable to the system, hindering operations, as some radars may not re-route information back to the head office.

Along the lines of the foregoing system, OptaSense [26] is a hybrid and cost-effective border monitoring system whose makers claim robust protection. The system features a maturely-set software technology, which is able to work with monitoring systems such as UAVs. OptaSense is chiefly intended to monitor access routes for a more secure border environment, both along roads and in forests. The system tries to alter the asset deployment schema and offer not just portable, but also effective systems – aiming to improve on the inadequacies of existing systems [27]. Fibre installation and configuration along the border allow the system to work with other assets, such as cameras, and offer a secure means of providing data. The system also extends total coverage, capturing more, and greater, remote areas, and aiming for utmost security in the long term. The major drawback of this system, however, is that it requires deployment along an entire border, which entails a substantial pre-engineering cost. In addition to this, the software platform used requires user training. OptaSense equipment has the reputation of raising a number of false

Table 1. Summary of Advantages and Disadvantages of Systems Reviewed in this Paper.

Product Name/ Technology	System Description	Objectives	Limitations
Change Detection Phenomena	Captures and records images and information from a particular place at two different instances.	Designed with consideration of monitoring different geographical areas.	Susceptible to natural conditions such as cloud cover.
EUROSUR	Satellite-based monitoring systems facilitate cooperation and 24/7 communication between EU member states authorities.	Supports authorities in reducing the number of illegal immigrants.	Complex coordination and technical operation.
DOLPHIN Surveillance	Decision-making and diplomatic resolution. Governed by EUROSUR.	Aims to stop cross-border crimes, drug trafficking and reduce the death toll of immigrants.	Sea-based border system; for the EU use only.
EVPU Surveillance	Customer-driven design and product development for mobile and fixed monitoring systems.	Designed for short-range surveillance, reliable, monitoring of borders and airports.	The Czech Republic uses only; prone to errors; requires intensive human involvement.
Helios	Consists of fibre-optic cables, lasers, and detectors.	Distributed acoustic sensor relies on the phenomenon of optical backscattering for its operation.	Only covers a maximum of 50km.
WESTMINSTER	Impenetrable security solutions to prevent border crossing and high-quality service.	Prevents or reduces the death tolls of illegal human trafficking through increased rescue operations and eliminates illegal immigration by sea.	Suffers from inaccuracies; deployed in border-sensitive areas only.
BorderSense	Hybrid system makes use of the technologies and facilities available.	Minimal human involvement, under-the-surface sensing devices, mobile nodes and use of heterogeneous devices.	Requires complex installation.
Cassidian	Customer demand-based highly-integrated border surveillance.	Offers border sensitive networks, secure and encrypted end-to-end communications, artificial intelligence system, and mobile command systems.	The expensive infrastructure required for deployment.
FLIR	The system is portable, cost-effective and can be used anywhere.	Uses the latest technologies and offers a 360-degree system.	Capital intensive; high False alarms rate.
Thales Border Surveillance System	Offers wide-ranging border surveillance systems, including standalone equipment, sensors, logistic support, training tools and services.	Offers a secure IT line, modern and complete turnkey and integrated border management system.	Assumption-based cooperation with neighbouring countries; thicker and denser areas may be impenetrable; re-routing problems.
OptaSense Border Security	Cost-effective, mature software technology for working with monitoring systems.	Eliminates existing fibres and covers larger areas.	Difficult to master; unreliable alarms.
ISIS	Approved by the DHS. Makes use of ISIS, drone-powered monitoring, and remote video surveillance (RVS), and can be impenetrable in places.	Provides advanced remote video surveillance, physical sensors, underground sensors, uses the seismic waves principle and seismic-powered sensors and offers migration cover in targeted areas.	Not designed to provide coverage to the full border.
Radiobarrier Security System	Governed by POLUS-ST, rapidly installable perimeters and critical infrastructure security.	Creates solutions to unresolved glitches and can be deployed rapidly.	Intensive human involvement.

alarms, making it unreliable in the event of a genuine threat to a border [26].

Another hybrid system discussed here is the Integrated Surveillance Intelligence System (ISIS), which is managed by the US Department of Homeland Security (DHS). ISIS delivers the latest technologies, e.g., drone-powered monitoring, sensors, and Remote Video Surveillance (RVS). Its key goal is to detect and prevent illegal crossing to the US [28]. Essentially, the objectives of this project are to offer more advanced RVS and physical sensors for detecting movement in the target areas. The system can only monitor a targeted area of interest, however, and cannot provide coverage of the full border [29].

Radiobarrier [30] is one of the surveillance systems introduced by POLUS-ST Ltd for line monitoring of the international border. Radiobarrier makes use of all the latest technological advances. POLUS-ST Ltd works towards developing rapidly installable perimeters and critical infrastructure security. As a result, Radiobarrier is the perfect system in urgent situations, where rapid intervention is needed. Generally, the objective of the company is to find solutions for any unresolved gap on a monitored border. There is, however, a lack of detailed technical information about the Radiobarrier system so it is difficult to judge its actual performance in the field. The main limitation of Radiobarrier is the intensive human involvement, which is required for installation right through to decision-making [30].

The advantages and disadvantages of the systems reviewed in this section are summarised in Table 1. This summary provides the basis for suggestions made for improved border-monitoring solutions.

3. Limitations of Current Systems

The majority of existing border monitoring techniques or systems reviewed in the previous section can only claim robustness and reliability in limited scenarios, with limited networks of sensors, with limited video footage, limited fault tolerance, and for a small variety of landscapes.

Not all present solutions build complex models of the observed spatial and temporal evolution of a scene. Another limitation in existing surveillance systems is the degree of accuracy and range of coverage that they each provide. Another key issue encountered in newer surveillance systems include the high false alarms that occur due to natural factors such as wind and animals.

Current systems solve these problems from different angles depending on their individual applications. The focus is on applications' perspectives rather than on developing general solutions that suit applications sharing the same deployment requirements. There is a need for new surveillance systems to close the gap between the existing systems and their limitations. New innovative solutions must be developed that can combat the shortcomings summarised in Table 1.

According to Giompapa et al. [1], there are five factors that must be considered when developing border monitoring systems:

1- There are a high number of potential threats, and this could be irregular.
2- Surveillance operations occur during peace conditions.
3- Many environmental elements can lead to confusion and cause distraction.
4- Threat detection and identification can be made more complicated by the use of covert technologies.
5- The monitored area is typically vast and requires huge physical resources to cover.

These five aspects, if taken into account when creating border solutions, can ensure a better monitoring system and, hence, more secure borders. They also address possible vulnerabilities as well as the identification of capabilities of the system. The use of stealthy methods for detection and surveillance, for instance, Wireless Sensor Network (WSN) technology, makes this task further challenging. The installation of surveillance devices under the ground or in a hidden location can make them more effective, because they are concealed from the naked eye and, so, their operation cannot be disrupted. Usually, borders constitute a large geographical area that is a combination of both rough and plain terrain, and use of devices is preferred that are more solid, long-lasting, effective and compatible with other devices already in place. WSNs if added to a border monitoring setup, can take the surveillance process to a new level, since the sensor networks directly reduce human dependency and work on an embedded artificial neural network. A fully-embedded WSN possesses all the essential components, which are needed for successful border monitoring and combats or does not exhibit many of the disadvantages of the systems outlined in Table 1.

Current systems successful operation is subject to the physical presence of humans, or at least the actual intervention and supervision of humans. They also require huge capital investment in software and hardware resources. Moreover, full coverage of the monitored area is an important aspect of any surveillance system. The coverage must be combined with on-time delivery of information; late data delivery will result in the failure of the surveillance mission as most situations require spontaneous intervention and response [31].

Another major challenge is the line-of-sight factor that curtails functioning and prevents monitoring behind walls or, in fact, or any type of physical obstacle. Many existing systems suffer from this defect, which degrades their performance not just in terms of long-range detection, but also in terms of the expenditure incurred due to the repetitive installation of surveillance units. All these factors call for an effective and dynamic surveillance system, which will enable more accurate monitoring that is less dependent on human intervention and is much more effective in terms of range and accuracy.

Requirements for a New Border Surveillance System

Given the sheer length of international borders, there is an increasing demand to make border surveillance systems less reliant on human intervention or supervision. Human intervention takes many forms, from guards patrols to command centres personnel. Besides the cost incurred by employing more people and training them to operate border monitoring systems, there are concerns over the efficiency of humans managing such a large-scale mission, e.g., corruption, and sometimes their safety. Moreover, humans cannot be deployed in some hostile terrains, e.g., deserts. As such, there is a need to establish new surveillance systems that are compatible with and versatile in variable circumstances. Such a system should be modelled in such a way that adjustments can be made without disrupting the operation of the entire system, or completely reconfiguring every surveillance device. Monitoring devices must be multi-hop communication enabled, which supports network scalability. For instance, sensor nodes have severe resource constraints, which necessitates careful planning of their resources without risking the overall system throughput. Energy consumption is another challenge in the monitoring of remote areas, where nodes cannot be maintained or replaced at regular intervals. WSNs possesses many of these key features, which makes them a key element to an effective border surveillance system. They are low-cost, self-powered, self-configuring, autonomous devices equipped with a variety of sensors. WSNs comes with methods, tools and techniques to maximise their lifetime and adapt to failures without service interruptions. Moreover, WSNs can be deployed covertly and beyond the enemy lines. They can complement data collected by other technologies, e.g., satellites.

Deploying WSNs at international borders for surveillance and security has significant advantages over current systems, but it introduces new challenges. An effective remote surveillance system must take into account the following major issues towards achieving a successful WSN deployment for border surveillance:

1- QoS, e.g., real-time data delivery, error rates, etc.
2- Power efficiency to extend the lifetime of the system.
3- Reducing downtime by offering coverage redundancy and self-healing features.
4- Can be deployed in harsh environments and beyond enemy lines.
5- Their simple architecture limits the need for over-constructor resources.
6- Efficient communication techniques for relaying data over long distances.
7- Efficient MAC protocol that adopts duty-cycle technology to deal with inactivity periods.

Efficient MAC protocol is one of the methods being developed and employed to support border surveillance purposes. Two main challenges must be addressed in the MAC protocol: energy saving and on-time data delivery; maximising node lifespan through applying duty-cycle MAC protocols that send nodes to sleep in idle times.

New deployment strategies specific to WSNs are needed to fill the gaps in existing knowledge and technology. The aim of this deployment method would be to support heterogeneity, scalability and energy efficiency. A network must adopt heterogeneous node deployment that allows for different nodes' capabilities and functionalities. For instance, some nodes sense emotions, while others might sense temperatures. This introduces the need for effective data filtering, fusion and analysis methods. Given the disadvantages of current protocols and techniques, a new border security platform is required.

4. The Need for a New Border Monitoring System

Similar to border monitoring, other applications such as gas/water pipeline and railway monitoring, require high levels of security. The aforementioned applications share the same linear infrastructure that can run over thousands of kilometres. Any interruption to these applications might affect public and national security. An interruption could lead severe financial crises or major security threats. For instance, in late April 2014, a gang of thieves managed to steal thousands of gallons of diesel from Britain's most important pipeline that runs the 130 miles from Fawley refinery to the West Midlands [32]. A similar incident happened in Nigeria when some community members stole oil from the national oil pipeline and the spiralling cost of oil theft in 2013 was one billion pound a month [33]. This not only disturbed the security forces and energy prices but also had an impact on the environment as it caused significant pollution. Another example is railway disruption, which can lead working nations into massive interruptions when a break in the main railway links is caused.

These examples highlight the importance of having secure infrastructures that are able to stop any disruption that might occur, or even prevent it in the first place – something that an ideal border solution should also do. They also highlight a number of challenges. The infrastructures mentioned are national property and they are costly to deploy. However, such expensive property is the vital backbone of public need in any modern society. Such important systems require high-capability security monitoring systems that allow on-time surveillance a minimum cost. This raises the necessity of developing a completely generic system that is able to provide an appropriate level of security for many applications including border monitoring.

In developing an integrated framework for border monitoring, such a framework will adaptively utilise various approaches to border monitoring in order to maximise the amount and quality of monitoring information whilst minimising resource utilisation. By providing this standardised framework, we anticipate promoting interoperability and information integration. The best border monitoring system should integrate various technologies to achieve high performance and accuracy. Implementing WSNs will assure systematic coverage that fills the gap in other surveillance systems – their numerous advantages listed in Section 2 warrant this conclusion. It is worth mentioning that WSN systems can utilise various types of sensors to detect different variables such as acoustic, vibration, chemical, environmental changes, weather factors, humidity, flow, position, angle, displacement, distance, speed, light, video, etc. In addition, when deployed beyond enemy lines, WSN technology can be deployed to raise early alarms to prevent potential threats to a border rather than flagging an incident when it has already happened.

The new framework can also be used in all other WSN applications. This paper focuses on these applications because they raise a number of challenges for this research area in the future. There are many approaches for addressing these applications; however, they are rather expensive, unreliable, and difficult to implement. We believe it is more feasible to deploy WSNs in these areas of application in order to achieve easier installation, better quality of service, and energy savings.

5. Conclusion

There is no perfect technology, each technology has specific features that work well in certain situations. The authors believe that a carefully designed WSNs can prevent risk from occurring in border surveillance systems. It is also worth mentioning that hybrid systems that encompass the features of various systems that are available would serve the purpose of border monitoring more efficiently. Taking the positive features of all systems and leaving behind their respective drawbacks will enable the building of a hybrid system, which is not just efficient, but functions according to the needs of the hour in terms of border surveillance.

The hybrid system should work independently of natural changes in the form of rain, and storms, and be compatible with deserts and other barren parts of borders. While reliability depends directly on the sensor networks, a linear approach and accuracy of measurements through the linear aspect can help in improving the entire process. With the proposed new framework and a greater reliance on WSN technology, it is hoped that the difficult modern challenges in the field of border security can be better overcome.

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