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Artículos de investigación

System for early warning in hostile areas in the context of the military applications

Sistema de alarma temprana en áreas difíciles en el contexto de las aplicaciones militares

Sistema de Alerta Precoce em Áreas Difíceis no Contexto das Aplicações Militares

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ABSTRACT

In the context of the Colombian armed conflict, the army is responsible for conducting control operations in challenging terrains where illegal armed groups operate. These operations face significant risks, including surprise attacks that may result in temporary or permanent injuries, loss of fundamental rights, and, in some cases, death. Therefore, it is crucial to equip army personnel with tools that enhance the security of communities and reduce the negative impacts of risky situations, such as ambushes. This study describes the design of the Tactical-Passive Early Warning System (SATP), created to assist mobile patrols in control operations, involving the development of two prototypes: SATP-1 and SATP-2. The SATP-1 provided data that informed the creation of the improved SATP-2 system, which utilises passive infrared (PIR) sensors and radio frequency communication. This portable and low-cost system is easy to use in the field. Testing demonstrated excellent performance, with a night-time detection rate of 94.2% and a 93% detection rate indoors under intense lighting conditions. Such developments can also be applied to other fields requiring high levels of security in complex or expansive areas, such as the agriculture sector.

Keywords: Passive alarm, passive infrared sensors (PIR), mobile patrol, surprise attacks.

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RESUMEN

En el conflicto armado colombiano, el ejército es responsable de realizar operaciones de control en terrenos difíciles en el que operan grupos armados ilegales. Estas operaciones enfrentan riesgos significativos, incluyendo ataques sorpresivos que pueden resultar en lesiones temporales o permanentes, pérdida de derechos fundamentales y, en algunos casos, muerte. Por tanto, es crucial dotar a los miembros del ejército con herramientas que aumenten la seguridad de las comunidades y reduzcan el efecto negativo de las situaciones de riesgo, como las emboscadas. Este artículo describe el diseño del sistema de alerta temprana táctico-pasivo (SATP), creado para asistir a las patrullas móviles en operaciones de control, desarrollando dos prototipos: SATP-1 y SATP-2. El SATP-1 proporcionó datos que llevaron a la creación del sistema mejorado SATP-2, el cual utiliza sensores infrarrojos pasivos (PIR) y comunicación por radiofrecuencia. Este sistema portátil y de bajo costo es fácil de usar en el campo. Las pruebas demostraron un excelente rendimiento, con una tasa de detección nocturna del 94.2% y del 93% en interiores con intensa luz. Este tipo de desarrollo también puede aplicarse a otros ámbitos que requieran altos niveles de seguridad en áreas complejas o extensas, por ejemplo, en el sector de la agricultura.

Palabras clave: alarma pasiva, sensores infrarrojos pasivos (PIR), patrulla móvil, ataques sorpresivos.

RESUMO

No conflito armado colombiano, o exército é responsável por realizar operações de controle em terrenos difíceis onde operam grupos armados ilegais. Essas operações enfrentam riscos significativos, incluindo ataques surpresa que podem resultar em lesões temporárias ou permanentes, perda de direitos fundamentais e, em alguns casos, morte. Portanto, é crucial fornecer aos membros do exército ferramentas que aumentem a segurança das comunidades e reduzam o impacto negativo das situações de risco, como emboscadas. Este trabalho descreve o projeto do Sistema de Alerta Antecipada Tático-Passivo (SATP), criado para auxiliar patrulhas móveis em operações de controle, desenvolvendo dois protótipos: SATP-1 e SATP-2. O SATP-1 forneceu dados que levaram à criação do sistema aprimorado SATP-2, que utiliza sensores infravermelhos passivos (PIR) e comunicação por radiofrequência. Esse sistema portátil e de baixo custo é fácil de usar em campo. Os testes demonstraram um excelente desempenho, com uma taxa de detecção noturna de 94,2% e de 93% em ambientes internos com luz intensa. Esse tipo de desenvolvimento também pode ser aplicado em outros contextos que exijam altos níveis de segurança em áreas complexas ou extensas, como, por exemplo, no setor agrícola.

Palavras-chave: alarme passivo, sensores infravermelhos passivos (PIR), patrulha móvel, ataques surpresas.

Introduction

Colombia has endured an armed conflict for over 50 years, deeply affecting its society and military forces. Despite numerous efforts at both local and international levels to address the conflict, it remains a critical issue. Rural areas, in particular, have become strategic hubs for illegal operations due to their inaccessibility and limited state presence. Soldiers conducting territorial control operations face significant risks from ambushes and surprise attacks, often resulting in severe injuries or loss of life. The conflict has also had devastating consequences for civilians, particularly in rural regions where illegal activities thrive due to the absence of state control and geographical challenges (Aguilera, 2019; Ejército Nacional de Colombia, 2017; Fajardo, 2013).

The risks associated with these operations are multifaceted and extend beyond immediate physical harm. One of the most pressing concerns is the loss of human lives, including the deaths of officers, non-commissioned officers, and soldiers who are crucial to the operational effectiveness of the Colombian Army. These losses have a direct impact on the morale and cohesion of military units, further complicating the already challenging task of maintaining territorial control. Additionally, the conflict leads to an increase in combat-related injuries, many of which result in long-term disabilities that not only affect the individuals involved but also place a significant burden on military medical and logistical resources.

Another critical aspect is the financial strain imposed by the conflict. Military operations in high-risk areas often require substantial investments in personnel, equipment, and logistics. The loss of resources due to enemy attacks or operational failures significantly increases the overall cost of these missions. Furthermore, the Colombian Army must allocate funds for compensating victims of the conflict, including both military personnel and civilians affected by ambushes or attacks. This financial burden exacerbates the operational costs and limits the availability of resources for other critical areas of national defence.

These risks are further compounded by operational challenges posed by Colombia's dense jungle environments, characterised by unstable surfaces, dense vegetation, and extreme weather conditions. Soldiers often face additional threats, such as improvised explosive devices (IEDs), limited visibility, and logistical obstacles. Mobile patrols exposed to such conditions operate under significant psychological pressure. A professional soldier expressed this reality:

> We are tired of hearing of tactical cases in our area of operations, where every night was an eternity for each of us, at our mobile patrol bases waiting for the tranquility and silence to be interrupted; the hardest part is waiting for something unknown, knowing our lives are at maximum risk.

The lack of energy infrastructure in these remote areas further exacerbates operational challenges. According to the Institute for Planning and Promotion of Energy Solutions for Non-Interconnected Zones (IPSE, n.d.), these regions lack a consistent energy supply, leaving troops to rely on alternative solutions such as portable generators. However, these solutions are often impractical due to the terrain and weather constraints. Such conditions underscore the need for autonomous, energy-efficient systems designed to function in resource-constrained environments, ensuring troop operability and mitigating the risks of ambushes and other surprise attacks.

In this context, the proposed device in this research is particularly suitable for military operations. It is equipped with long-lasting batteries, requires no external energy supply, and offers high portability and adaptability. By not emitting signals or sounds that could alert the enemy, the device provides a significant tactical advantage for troops operating in high-risk areas. Unlike other systems, which may rely heavily on telecommunication infrastructure or require extensive training, this device bridges critical gaps, enabling immediate deployment in hostile environments.

From a theoretical perspective, this study builds on national and international research in human detection and perimeter security technologies. Advances in object detection using infrared, radar, vibrational, and electrostatic sensors have shown significant potential in security applications (Alwan et al., 2006; Buyukakkaslar et al., 2024; Castaño-Gómez et al., 2022; Jin et al., 2012; Tanaka et al., 2014; Yarovoy et al., 2006). However, despite their promise, existing systems often exhibit limitations in challenging environments such as dense jungles or mountainous regions. For example, many systems require extensive training, generate noise, or rely heavily on telecommunication infrastructure. In some cases, they emit light, which can inadvertently alert intruders during night-time operations (Han et al., 2024).

Nationally, the Colombian Army has developed systems to address these challenges, such as Indumil's SIDEPAM system and the Phantom Fox early warning system (Castaño-Gómez et al., 2022; Indumil, 2023). SIDEPAM, designed for point defence, uses explosives to alert patrols to potential intruders. While effective in specific scenarios, it requires fully trained personnel and relies on complex equipment, including explosive vests and detonators (Baranwal et al., 2016). Similarly, the Phantom Fox system employs wireless transmission modules based on infrared sensors and radiofrequency communication. This system sends alerts via Bluetooth to an Android device, allowing users to view maps of sensor locations. However, its dependence on Android devices and the potential visibility of light-emitting screens at night limit its applicability in hostile environments (Han et al., 2024).

The SATP prototypes represent a step forward in addressing these challenges. By leveraging passive infrared (PIR) technology for human detection and integrating wireless communication, the SATP prototypes deliver timely alerts without relying on complex infrastructure. Preliminary tests conducted in simulated jungle environments revealed detection rates of 94.2% for SATP-1 and 93% for SATP-2. The slight difference in performance is attributed to design modifications aimed at enhancing portability and reducing power consumption. Despite these variations, both prototypes demonstrate superior performance compared to existing systems, offering significant advantages in terms of portability, cost-efficiency, and adaptability.

This study aims to overcome such limitations by proposing a portable, low-cost, and easy-to-implement system capable of operating in resource-constrained environments. By addressing the operational and financial challenges posed by the conflict, the SATP system contributes to enhancing troop safety while optimising military resources.

This paper is organised as follows: the Methodology section details the development process of the SATP-1 and SATP-2 prototypes, as well as the field-testing procedures. The Results section presents the precision levels achieved by the SATP-2 under various operational conditions. Finally, the Discussion analyses the study's implications and limitations, highlighting potential areas for improvement in future implementations.

Methodology

The development of the device was carried out using a mixed methodology with an experimental approach. Two versions of the prototype were designed: SATP-1 and SATP-2, which were subjected to multiple laboratory tests. This allowed for continuous improvements to the device, considering the recommendations of expert personnel frequently present in the operational area. Additionally, tests evaluated the system's effectiveness under field conditions and controlled environments across various locations and timeframes. This approach ensured that the device operates properly in any situation, in line with the needs of military operations.

In the study, various electronic designs were developed to enable constant communication and an optimised power system, given that military personnel operate in remote areas lacking energy supply and communication lines. Consequently, a device was designed to maintain seamless communication between the transmitter and receiver, while offering extended battery life.

During laboratory tests, it was verified that the sensors adequately recorded data or signals. Additionally, an electronic circuit was designed to guarantee voltage protection. Furthermore, a control system was developed to accurately detect individual presence using infrared sensors.

These functions were evaluated in two stages: the first was conducted in a controlled open field (see Figure 7), where there were no obstacles, to verify the proper functioning of the device in the areas of transmission, data processing, and energy system. In the second stage, a test exercise was carried out in a rural area, aiming to assess performance under conditions with natural obstacles that are common in the jungle areas frequented by Colombian soldiers (see Figure 8).

This section describes the stages of developing an early passive warning system, SATP. To this end, the main system requirements were defined by consulting professional soldiers, identifying the main characteristics of the reported systems, and establishing the working scenario. As such, the identified scenario is when a patrol conducts operations in rural areas where the soldiers implement the security protocols within a perimeter, in which some soldiers are the sentinels while the others take a break or rest at night. In this scenario, the group's lives depend on the sentinels, while at the same time, they are also the main target of possible attackers. Accordingly, the system requirements are defined based on selected characteristics shown on Table 1.

Table 1.

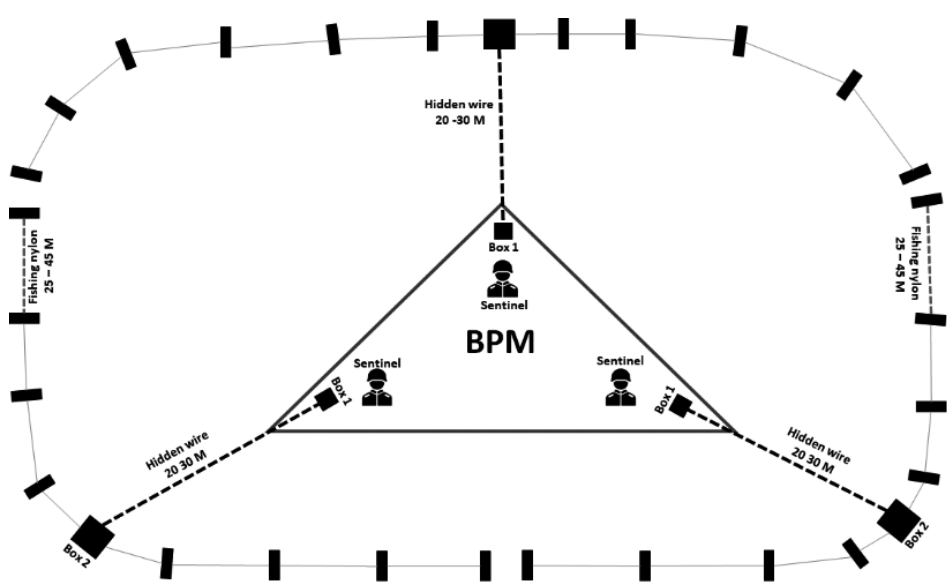
Comparison of some characteristics of reported systems and the proposed SATP for assisting early warning human detection in critical areas in control operations

Characteristic	Sidebafi (10)	SAT (10)	Phatom fox (11)	Proposed prototype SATP-1 (13)	Proposed prototype SATP-2
Mechanical detection system	✓	✓	×	✓	×
Wireless detection system	×	×	✓	×	✓
Electrical operation	×	✓	✓	✓	
Soundless or low-luminosity alarm signal, reusable after activation	×	✓	✓	✓	✓
Alert operating time suitable for the duration of the mobile and semi-mobile patrol base.	×	×	✓	✓	✓
No explosives required	×	✓	✓	✓	✓
Easy to use	×	✓	×	✓	✓
Easy to install	×	✓	×	×	✓
Quick setup	×	✓	×	×	✓

The first prototype (SATP-1) was conceived to be implemented in the scenario illustrated in Figure 1. As shown, this is a wired system based on mechanical principles, similar to the SIDEBAFI or Early Warning System (Castaño-Gómez et al., 2022). For practical use, common factors in the areas of operation were considered, including mechanical activation mechanisms and the availability of supplies. Accordingly, the system comprises two modules: the electronic module and the mechanical module, whose elements include nylon, AA batteries, LEDs for flashlights, wire, and wooden stakes (see Figure 2). The electronic module is managed by the sentinel, while the mechanical modules are located at critical points, as shown in Figure 1.

Figure 1.

Scenario and setup of the SATP-1



Source: Adapted from Ejército Nacional de Colombia, 2017.

Figure 2.

Setup of the SATP-1

Source: Adapted from Institute of Metal Science High-Tech (2023) and Rincón (2021).

Its functioning relies on a simple principle: changes in the nylon determine whether to activate a luminous signal in the electronic module. Specifically, tension or strain relief generated by the nylon triggers the electronic module to activate the LEDs, serving as an alarm for the sentinel.

The SATP system is designed to detect intruders within the security perimeter of a mobile patrol base (MPB). To achieve this, the system leverages the advantages of passive infrared (PIR) motion detection sensors and radio frequency (RF) communication. These technologies enable the development of a portable, low-cost system that allows for easy setup in real-world environments without requiring extensive preparation by military personnel.

Specifically, the system consists of two main components: a transmitter module and a receiver module. The transmitter module houses the motion detection unit with PIR sensors, while the receiver module functions as a silent alarm carried by the sentinel, activating upon detection of an intruder within the security perimeter. Motion detection in approach avenues is performed tangentially in an arc of ±100° and radially up to ±9 metres (see Figure 3). Additionally, the system can function with a distance of up to 100 metres between the transmitter and receiver modules, configured in setups such as the one illustrated in Figure 4.

Despite the benefits of the SATP-1 system, certain limitations were identified during its deployment. These include the following: the installation protocol requires additional time due to the synchronisation of mechanical components; the sentinel must monitor the system continuously throughout the night; the lack of a recharging mechanism limits operational efficiency; and the system's reliance on wired connections restricts the sentinel's mobility (Buyukakkaslar et al., 2024; Nurhidayat & Suratman, 2024).

To address these limitations, a new model, SATP-2, was developed to support mobile patrols in scenarios similar to the one depicted in Figure 4. The SATP-2 system provides wireless support while maintaining the functionality of PIR sensors (Kaul et al., 2024; Lei et al., 2010). It consists of a receiver module and a transmitter module, connected via radio frequency (RF) communication protocols. The transmitter module includes the PIR motion sensor, designed to detect individuals approaching the perimeter, while the receiver module integrates a vibrational device to silently alert the sentinel. The PIR module incorporates two SMD32 pyroelectric sensors, an TX/RX HC-12 RF communication card, and a 3.7v 2000mAh lithium-ion battery (see Figure 5). The block diagram of the system is presented in Figure 6, detailing the electronic components of both modules (Almomani et al., 2021; Cui & Dahnoun, 2021).

Figure 3.

Approach Avenue Diagram

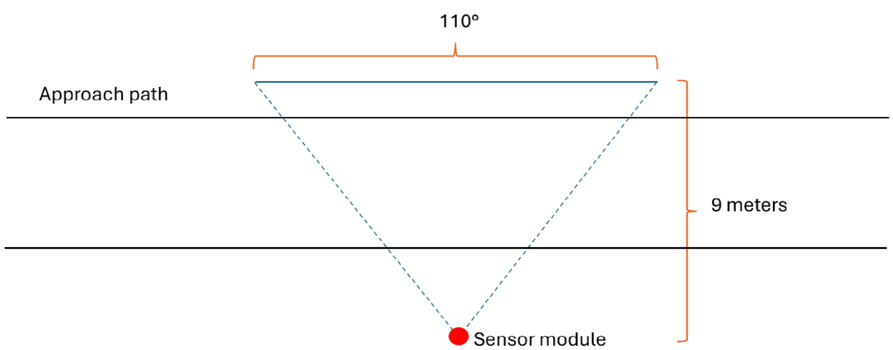


Figure 4.

Set-up of a mobile patrol's occupancy

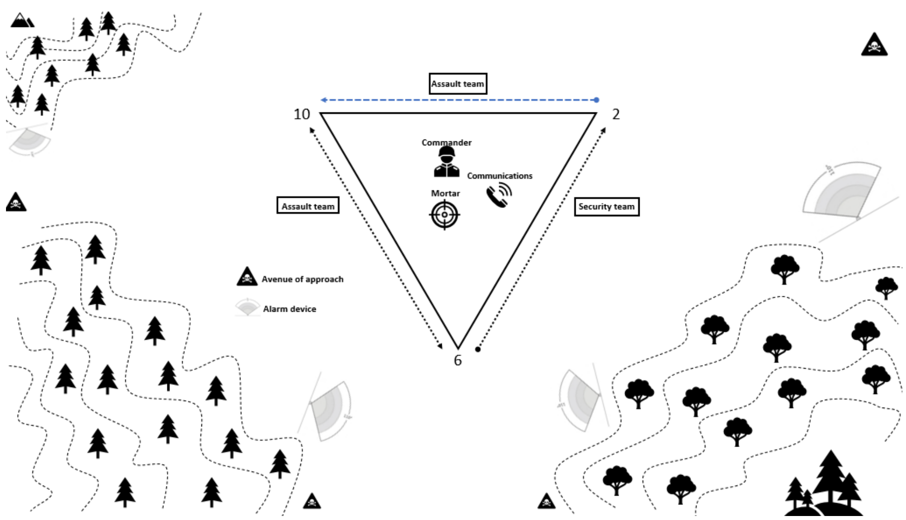


Figure 5.

Prototype of the wireless SATP-2

The SATP system is designed to detect intruders within the security perimeter of a mobile patrol base (MPB). Leveraging passive infrared (PIR) motion detection sensors and radio frequency (RF) communication, the system offers a portable, low-cost solution suitable for military operations. These technologies allow rapid deployment and adaptability to challenging terrains without extensive preparation by personnel.

The SATP system consists of a transmitter module and a receiver module. The transmitter houses the PIR sensors to detect motion within a ±100° arc and up to 9 metres radially. The receiver module serves as a silent alarm carried by the sentinel, triggering a vibration upon detecting an intruder. These modules communicate wirelessly, ensuring mobility and discretion for the sentinel.

The first version, SATP-1, was limited by its reliance on wires, lack of recharging capabilities, and the need for continuous monitoring by the sentinel. These constraints, identified during field tests, underscored the need for improvements (Buyukakkaslar et al., 2024). Consequently, SATP-2 was developed, featuring wireless communication, extended battery life, and improved mobility. By integrating two SMD32 pyroelectric sensors, an HC-12 RF communication card, and a 3.7v 2000mAh lithium battery, the SATP-2 ensures robust performance in resource-constrained environments.

The SATP-2 incorporates a battery monitoring feature that signals when the battery reaches 50% capacity, ensuring recharging before depletion. This enhancement addresses critical operational needs, particularly during early morning hours, when most surprise attacks occur (Ejército Nacional de Colombia, 2017). The system's improvements significantly enhance its usability, reducing set-up time and eliminating the sentinel's continuous monitoring.

To evaluate the prototype's detection performance, two tests were designed to assess the detection angle range and distance. The first test was conducted indoors within a hall with high-intensity light, as shown in Figure 7a. Specifically, a subject walked ten times within the system's detection angle range (110°) at distances between 0m and 9m (see Figure 7b). The second test was conducted outdoors at night, simulating conditions where intruders are more likely to appear during field operations. As in the first test, the subject walked ten times within the system's detection angle range (110°) at distances between 0m and 9m (Njanda et al., 2024).

Figure 6.

Scheme of the STAP-2 prototype

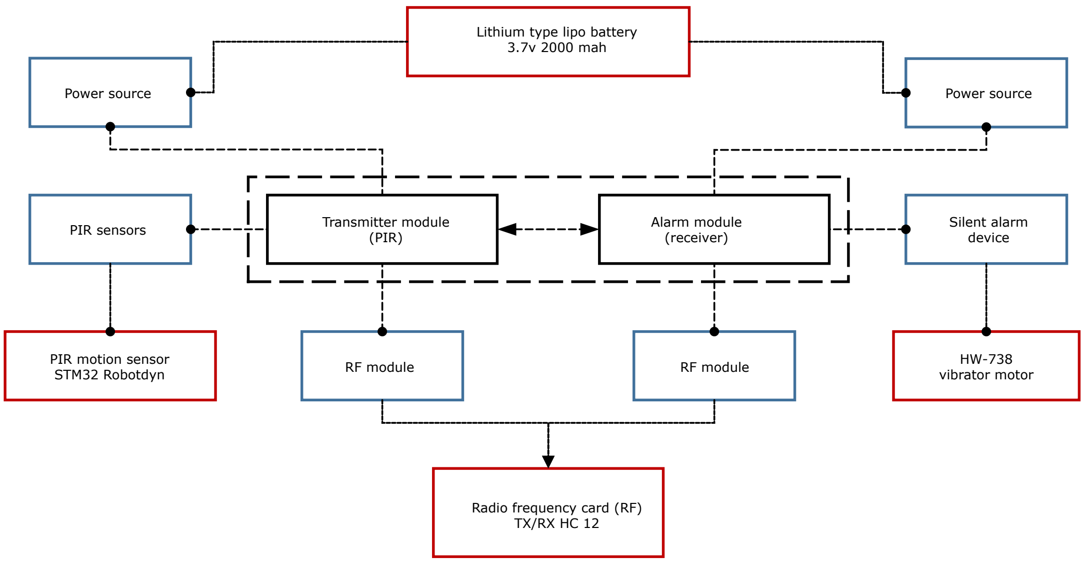
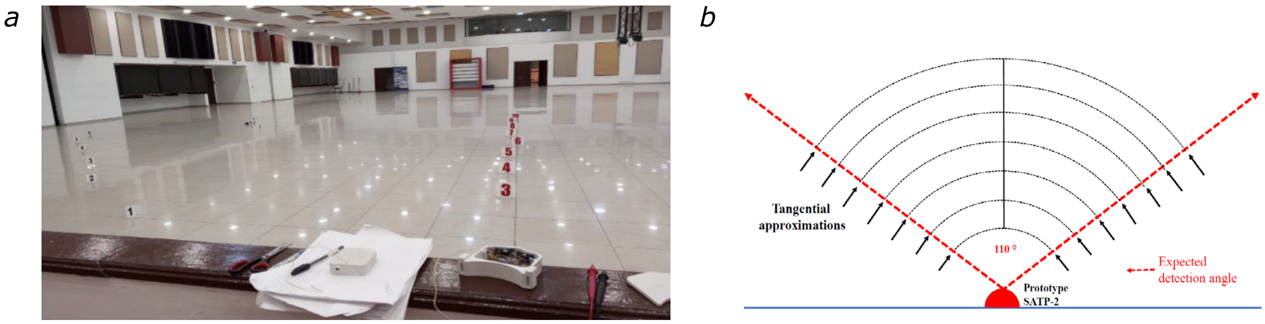


Figure 7.

a) Set-up of indoor testing; b) Detection cone



Results

The first prototype was previously deployed in operational areas where its functioning was tested with mobile patrol bases. The installation procedure can be found in greater detail in Rincón (2021). Here, we present its functionality, verified by checking the alarm activation mechanism. Namely, the system generates alerts indicated by LEDs whose states are adjusted to the possible responses in the operational area of the sentinel, as follows (see Figure 8):

- Single flash: low alert; action: verify and report.
- Two or more flashes: medium alert; action: verify and report.
- Full ON: alert the patrol, reaction.
- Simultaneous flashing of both LEDs: the nylon was cut; immediate reaction.

Although the second prototype, SATP-2 (see Figure 5) has yet to be used in the field, its functioning has been successfully tested. Furthermore, the main aspects of its set-up were established, for example, the PIR module should be located and camouflaged, preferably in an avenue of approach (see Figure 4) at a height of no more than one metre, while the receiver (RF module) must be delivered to the sentinel. The SATP-2 tested functioning was as follows: when the device is turned on, it automatically performs a diagnostic routine to check the status of its components and the charge levels of both the sensor and the receiver (see Figure 9). If the preconditions are optimal, the device initiates each module (RF module-PIR module). When an intruder enters the detection cone (see Figure 7b), an alert is sent to the receiver, which activates a silent alarm utilizing a HW-738 vibrating motor. Thereby, a warning is sent to the sentinel of a possible intruder; once the sensor stops detecting the event, it enters a latency period of three seconds, and then it activates again.

Figure 8.

A) The subject contacts the nylon, low and medium alarm. B) The nylon is cut, and immediate reaction is required. C) The LEDs are off because the state of the nylon is normal. Adapted from Institute of Metal Science High-Tech (2023) and Rincón (2021)

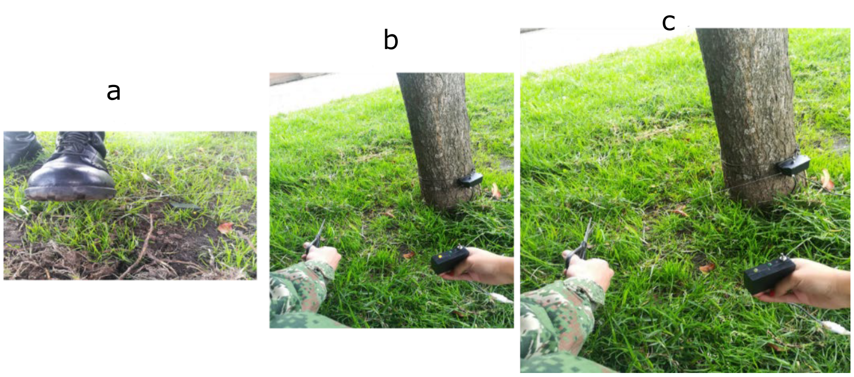
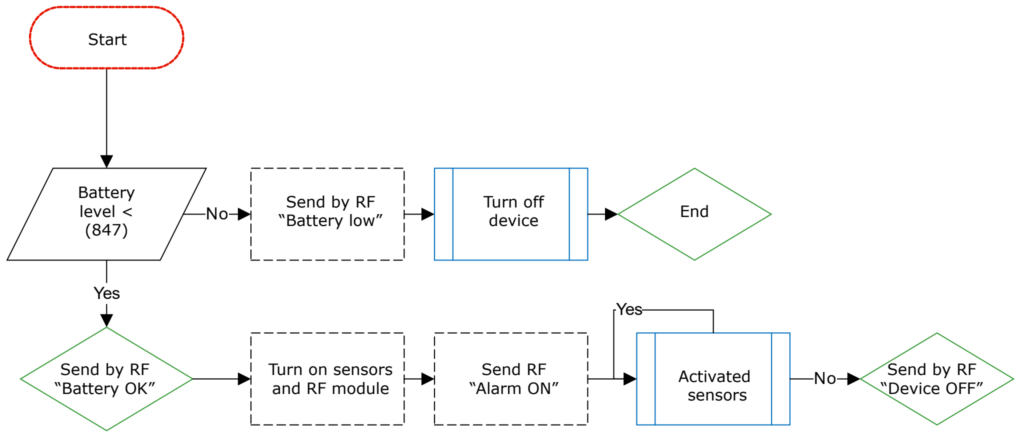


Figure 9.

Flowchart of the device (SATP-2) status check



The detection performance of the SATP-2 system was evaluated based on its hit rate, expressed as a percentage of successful detections. This evaluation included controlled tests conducted both indoors and outdoors to assess the system's reliability under varying environmental conditions, complementing the functionality discussed earlier in the methodology section. The results demonstrate the robustness of the system in detecting intrusions within its operational parameters.

As mentioned earlier, the prototype SATP-2 was first tested indoors. During ten walking trials conducted by the subject, the system accurately detected 112 events within the detection cone while erroneously detecting 8 events (see Figure 10a). This resulted in a hit rate of 93%. Under the high-intensity light conditions of the hall, the system exhibited proper functioning with a wider detection angle than expected. This behaviour, influenced by varying radiation conditions (Xing et al., 2024), suggests the possibility of similar performance outdoors during daylight.

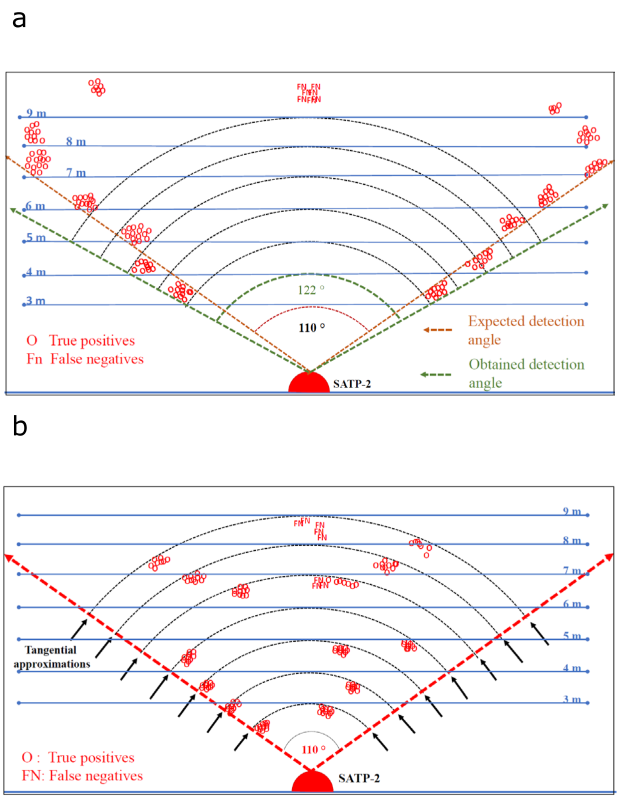
Similarly, the nighttime outdoor testing demonstrated excellent performance. The system correctly identified 132 detection events while recording only 8 false negative events, resulting in a hit rate of 94.2%. As illustrated in Figure 10b, the system operated effectively within its theoretical detection angle of 110°, consistent with the technical specifications of its PIR sensors. These results confirm the system's adaptability to operational scenarios with limited lighting, a critical factor in its deployment.

As highlighted previously, the difference in hit rates between indoor and outdoor tests emphasises the system's response to varying environmental factors. For instance, the higher hit rate observed during night-time outdoor testing may reflect reduced interference from ambient radiation, allowing the PIR sensors to focus more effectively on detecting movement. Conversely, the indoor tests, conducted under complex light reflections, provided valuable insights into the system's adaptability in environments with dynamic lighting conditions.

This consistent performance underscores the reliability of the SATP-2 system for military applications. Its ability to maintain a stable detection angle and high hit rates, regardless of environmental conditions, makes it a valuable tool for securing mobile patrol bases. Future research could further explore its performance in extreme conditions, such as rain or dense fog, to refine its capabilities and expand its operational versatility.

Figure 10.

Results of detection of SATP-2: a) indoors and b) outdoors at night



Discussion

The SATP-1, as a wired system with mechanical activation, faced significant limitations in terms of mobility and installation time. These constraints posed challenges for its practical application in dynamic operational environments, where rapid deployment and adaptability are essential. To address these shortcomings, the SATP-2 was developed, implementing passive infrared (PIR) sensors and wireless communication. This advancement simplifies the set-up process, enhances real-time response capabilities, and significantly improves operational security by reducing critical preparation times.

The SATP-2 demonstrated a detection rate of 94.2 % in night-time field tests and 93 % in indoor environments with high illumination. These results underscore the system's effectiveness under diverse conditions, highlighting its versatility. While reflective lighting during indoor tests caused minor reductions in precision, the system is optimised for night-time operations when military units are most vulnerable. During the day, units are generally on patrol, making the system's primary functionality most relevant during night surveillance, where the risk of ambushes and intrusions is heightened.

The integration of PIR sensors and wireless communication enhances the SATP-2's portability and ease of use, key factors in military operations. Its lightweight, compact, and wireless design makes it more practical for professional soldiers, enabling efficient deployment and transportation. These features are critical for missions where equipment utility and operational efficiency are priorities. Moreover, the SATP-2's robust and adaptable design ensures it can operate effectively in challenging environments, particularly in remote or hostile areas where technological infrastructure is limited.

Beyond its military applications, the SATP-2 also shows significant potential for use in civilian sectors. Its adaptability and low-cost design make it an attractive option for improving perimeter security in various scenarios. Specific applications include:

1. Agriculture: Protecting crops from intruders or animals, thereby preventing economic losses.

2. Protected natural areas: Monitoring parks and reserves to deter poaching or other illegal activities.

3. Critical infrastructure: Enhancing security at industrial plants, pipelines, and power grids in rural or remote areas.

4. These applications demonstrate the SATP-2's versatility across different sectors. Its portability and affordability make it particularly suitable for rural communities and areas where reliable perimeter security solutions are otherwise inaccessible.

Battery autonomy is another critical aspect of the SATP-2's design. Equipped with a 3.7V, 2000mAh lithium battery, the system is tailored for night-time operations, ensuring efficient functionality during critical periods. As previously mentioned, the system emits an alert when the battery level drops to 50 %, allowing for preventive recharges before the battery is completely depleted. This feature is vital for ensuring uninterrupted monitoring during high-risk periods, such as the early morning hours when surprise attacks are most likely. Proper battery management not only guarantees continuous operation but also prevents vulnerabilities during critical moments, thereby reinforcing the security of military personnel.

Future improvements could include integrating higher-capacity batteries or solar charging systems to extend the system's autonomy further. These enhancements would be particularly beneficial for long-term missions in remote areas where recharging options are limited. Additionally, the inclusion of modular components could allow for easier customisation and scalability, adapting the system to cover larger areas or to detect threats more effectively in complex terrains such as jungles or mountainous regions.

While the SATP-2 has demonstrated excellent performance in its current configuration, there remains room for improvement. Expanding its detection range would enable the system to cover larger operational areas, which is particularly important in environments with limited visibility or difficult terrain. Similarly, incorporating advanced technologies to mitigate the effects of daylight radiation on sensor performance could improve its reliability in broader contexts.

In conclusion, the SATP-2 represents a significant advancement in perimeter security systems, offering enhanced operational efficiency, portability, and versatility. Its ability to function effectively under varied conditions positions it as a valuable tool not only for military applications but also for civilian sectors seeking cost-effective and reliable security solutions. The promising results achieved thus far open new opportunities for continued development and optimisation, ensuring that the SATP-2 remains a cutting-edge solution for challenging operational environments.

Conclusions

In this paper, we presented the design of two prototypes aimed at supporting mobile patrols in order to increase their security in harsh and hostile areas of operations where they can be exposed to sudden attacks. The first prototype, the early warning system (SATP-1), was based on mechanical principles, which presented some disadvantages in the field. Therefore, a low-cost system was proposed (SATP-2), using passive infrared sensors (PIR) performance and wireless communication. All these components are placed on an electronic board designed exclusively for this prototype, including the charging and voltage verification systems for optimal operation. In this sense, the concept of SATP-2 has tactical advantages, given that the alert is only silently received by the sentinel, increasing the opportunity to take timely measures.

Furthermore, field tests have shown excellent results at night detection with a hit rate of 94.2 % and indoors with intense light, where the hit rate was equal to 93 %, validating its functionality and detection accuracy. These results emphasise the reliability of the SATP-2 under diverse conditions, demonstrating its potential for enhancing operational security in critical scenarios. Such results open avenues to explore improvements in covering larger distances, increasing detection angles, and mitigating the effects of daylight conditions that may affect sensor accuracy. Future work will include testing the SATP-2 under different conditions in the field, such as varied terrains and weather extremes. Additionally, its applications extend beyond military contexts, given its potential for use in domains such as agriculture, nature-protected areas, and infrastructure security.

Beyond its current design, the SATP-2 offers significant opportunities for advancement and broader implementation. By incorporating new communication systems, the SATP-2 could interact seamlessly with other devices, such as closed-circuit television (CCTV) systems or broader security frameworks, enabling its deployment in urban environments and critical infrastructure protection. Moreover, integrating improved deployment mechanisms would facilitate its use in more complex operational scenarios, ensuring compatibility with other technological systems. These advancements would not only increase its versatility but also make it an essential tool for security operations in both civilian and military domains.

Future research on the SATP-2 can follow two critical lines of investigation. The first focuses on optimising the device's performance through technological improvements. These include extending battery life to ensure longer autonomy in remote operations, refining wireless communication protocols to enhance reliability, and developing silent alert mechanisms that avoid alarming intruders. Such enhancements would ensure continuous functionality in high-risk missions and reduce vulnerabilities. The second research line emphasises the operational perspective. The integration of the SATP-2 into military doctrine would allow for more efficient offensive and defensive operations, aligning advanced technology with strategic planning to maximise mission success. This integration would require adapting training programmes and operational frameworks to fully leverage the system's capabilities.

The SATP-2 has demonstrated its capacity to enhance the safety and response capabilities of mobile patrol units operating in critical environments. Its lightweight, autonomous, and cost-effective design ensures it remains practical for use in remote missions with limited resources. Additionally, its adaptability allows for diverse applications, from protecting sensitive military assets to securing agricultural or protected areas against threats. These features highlight the system's versatility and its ability to address various security challenges.

The operational impact of the SATP-2 extends beyond its immediate technical benefits. By providing silent alerts and ensuring continuous monitoring, it strengthens perimeter security without exposing personnel to additional risks. The battery management system, which includes a charge alert at 50 %, ensures operational continuity during critical moments. Although future enhancements, such as integrating solar charging systems or higher-capacity batteries, could further extend its autonomy, the SATP-2 is already capable of supporting military operations for extended periods under its current configuration. This makes it a reliable and practical solution for long-term missions in remote or challenging terrains.

The SATP-2 is a significant step forward in the development of early warning systems, combining innovative technology with practical applications. Its ability to function autonomously and integrate seamlessly into operational planning makes it an invaluable tool for both military and civilian use. As new improvements are explored, such as expanded detection range, renewable energy solutions, and interaction with other systems, the SATP-2 will continue to evolve as a cutting-edge solution for high-risk environments. This development underscores the importance of investing in advanced technologies to enhance safety, improve mission success, and provide solutions that benefit both security forces and society at large. The system's design emphasises sustainability and efficiency, demonstrating that even in its current configuration, it can support long-term operations in remote areas with limited resources.

This system sets a precedent for the integration of technology into modern military doctrine. By aligning advanced systems with strategic planning, it fosters a hybrid operational approach where human expertise and technological capabilities work together to achieve mission success. This represents a transformative step in the way military and security operations are conducted, ensuring both safety and efficiency in increasingly complex operational environments.

Finally, the SATP-2 represents a significant step forward in the development of early warning systems, combining innovative technology with practical applications. Its ability to function autonomously and integrate seamlessly into operational planning makes it an invaluable tool for both military and civilian use. As new improvements are explored, such as expanded detection range, renewable energy solutions, and interaction with other systems, the SATP-2 will continue to evolve as a cutting-edge solution for high-risk environments. This development underscores the importance of investing in advanced technologies to enhance safety, improve mission success, and provide solutions that benefit both security forces and society at large.

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