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Antipersonnel landmines in the Colombian internal conflict: implications for technology development

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Abstract
The contribution of universities, companies, and the state in Colombia to confront home-made antipersonnel (AP) landmines has generated solutions and useful studies for many projects developed in the last 15 years, including for demining processes in Colombia. The construction of AP landmines has changed in the last 15 years, due to the intermittent nature of the internal conflict in Colombia. The office of the High Commissioner for Peace, Decontamina Colombia, shows that non-state armed groups have the strategy to cut the detonator of the home-made AP landmine to reduce its amount of metal. This document shows the aspects of the conflict that have affected humanitarian demining, which help the design and construction of technological devices. This article does not attempt to describe each technology used in humanitarian demining processes, but rather to show the characteristics considered in the design of two detection devices aimed at detecting home-made AP landmines.

Keywords: humanitarian demining; internal conflict; metal detector; landmine; ground penetrating radar.

Minas antipersona en el conflicto interno Colombiano: implicaciones para el desarrollo de tecnología

Resumen
El esfuerzo de universidades, empresas y el estado en Colombia para enfrentar las minas antipersona caseras ha generado soluciones y estudios útiles para muchos proyectos desarrollados en los últimos 15 años, incluso para procesos de desminado en Colombia. La construcción de minas terrestres antipersona ha cambiado en los últimos 15 años, debido a la intermitencia del conflicto interno en Colombia. Por ejemplo, como lo menciona la Dirección de Acción contra las Minas en su página web, los grupos armados no estatales recortan el detonador que contiene el explosivo primario para disminuir el metal en la mina. Este documento muestra los aspectos del conflicto que han afectado al desminado humanitario en Colombia, los cuales ayudan al diseño y construcción de dispositivos tecnológicos. Este artículo no pretende describir el funcionamiento de cada una de las tecnologías típicas utilizadas en procesos de desminado humanitario, sino mostrar las características que debe incluir el diseño de dos dispositivos de detección orientados a la detección de minas antipersona caseras.

Palabras clave: desminado humanitario; conflicto interno; detector de metales; minas terrestres; radar de penetración terrestre.

1. Introduction

Colombians still have in their minds the social and cultural changes generated by the country's internal conflict because we have experienced them at different times. State programs [1], publications [2-4], and the media [5-8] show the atrocities of this internal conflict in various rural regions of Colombia [1,2,9-11] as well as how home-made landmines

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have affected more than three generations of Colombians. However, defining the exact date from which non-state armed groups started using these threatening devices is a difficult task because there are no reliable sources of information. Understanding the beginning of this conflict could help us to analyze the causes that led these non-state armed groups to use home-made landmines and to avoid similar problems in a post-conflict scenario in which many rural regions would be able to live together in peace.

All actors in the Colombian conflict have used different types of landmines, but non-state armed groups constructed home-made AP landmines, such as improvised explosive devices (IEDs). These devices have greatly impacted the environment of rural communities because directly affect natural resources; therefore, this effect is the point of reference for developing state policies for humanitarian demining activities [1].

In Colombia, many rural communities, such as the Catatumbo region in the Department of Norte de Santander, even after the signing of the peace agreement, face social problems due to the presence of non-state armed groups and illicit crops and require technological developments that support all state programs. For this reason, the Colombian State requires mechanisms and tools to understand and confront all the situations that generate disturbances to these rural populations who wish for peace [12]. However, non-state armed groups have created different strategies to construct these IEDs with non-traditional components such as non-metallic containers and syringes as fuse components, which are difficult to detect using commercial devices.

Currently, many of the productive sectors in Colombia want to end the internal conflict so that rural communities can have more significant opportunities [13]. Therefore, following the complaint of several sectors in Colombia to end the internal conflict, the Colombian State and non-state armed groups signed a peace agreement in 2006. Despite this agreement, Colombia still has the presence of threatening IEDs because non-signing members of non-state armed groups have created criminal gangs (Bacrim in Spanish) that are using home-made landmines to protect illicit crops in regions such as the Catatumbo [14]. For these reasons, the clashes between these criminal gangs are due to their interest in dominating territories with illicit crops, which affects the later stage of post-conflict, including: respect for human rights, mobility between rural areas, creation of conditions that promote competitiveness between regions, creation of competitive agriculture, and expansion of access to education in rural areas.

In addition to the effects of non-traditional IEDs components, an additional aspect is the influence of the environmental conditions of the affected region and the type of home-made landmine. These two factors are complex issues that affect the clearance process. However, the continuing changes in the internal conflict also affect the clearance of the regions affected by these devices.

We found three characteristics that shape the problem caused by home-made AP landmines: 1) the impact generated by the use of these improvised explosive devices; 2) the investigations aimed at their detection; and 3) the historical context of the activities carried out by the Colombian state for their detection and eradication from the affected territories. These characteristics show that the number of events by AP landmines and UXO (Unexploded Ordnance) decreased in two years within the conflict (2009 and 2018), which coincide with the change of government in Colombia. However, due to the changing behavior of the internal conflict, the effect after these local minimums should be an increasing number of events. For the second minimum value of events, the subsequent increase is affected by the presence of illicit crops due to the presence of criminal gangs and other actors.

The clearance of home-made AP landmines requires two complementary aspects that reduce accidents with this type of device: detection and education programs. However, in Colombia, the victims generated by these threatening artifacts is a current issue that involves both the Colombian government and international organizations, such as the United Nations (UNMAS) and the International Committee of the Red Cross (ICRC). This paper focuses on the detection process in demining activities and shows the effects of two typical detection systems (Metal Detector and Ground Penetrating Radar). We associated the detection and effects of home-made AP landmines with the historical context, scientific papers, and their impacts in order to show the present problem; for this reason, we built our metal detector prototype for objects with low metal content by comparing the results of other scientific papers showing signals very similar to those of our prototype, including scanning procedures followed in demining activities.

This paper contains six sections showing home-made AP landmines' implications for any detection device. Section 2 shows the characteristics of the Colombian internal conflict. Section 3 shows scientific papers following a chronological order within the last 15 years. Section 4 shows the methods and tools used to visualize the effects (section 5) of home-made AP landmines on detection devices, and section 6 shows our conclusions.

2. Main characteristics of Colombian conflict

2.1. Internal conflict effect

The Colombian conflict is one of the 1,743 internal conflicts in the world. The conflict between the government of Russia (former the Soviet Union) and the Ukrainian Insurgent Army (UPA) is the oldest (1941-1959), while the conflict between the government of Jordan and the Islamic State is the most recent [15].

Internal conflicts in four regions of the world (Europe, Middle East, Asia and Africa) are related to government-territory and conflicts in the Americas are related to government. Some of the conflicts in the Americas (South and Central America) have lasted several years, even with intermittent periods with changes in the use of antipersonnel mines. The Colombian conflict has an outstanding feature: non-state armed groups have used strategies and tools to neutralize government decisions oriented to end the conflict, especially those related to antipersonnel landmine activities.

In Colombia, the effects of home-made mines are due to the way non-state armed groups use these IEDs to counter the offensive of the Colombian Army and to protect territories with illicit crops, which strengthens their political and economic strategies in rural communities.

Demining in Colombia involves two periods that allowed the Colombian State to use technologies and generate norms to mitigate the effects of home-made mines. In the first period from 2000-2012, the Colombian State sought the technology to detect home-made mines that best suited the different regions and mine action [16], which generated a reliable information system [17]. In the second period beginning in 2013, Colombia created national mine action standards so that non-governmental organizations can work as humanitarian demining organizations [1].

The changing behavior of the internal conflict prevents the characterization of home-made mines buried in rural regions, as well as the selection of the most suitable metal detector. Metal detectors used in the first period are different from those used today, due to the non-metallic components of home-made mines. This change of components affected the performance of metal detectors, but this is not the only reason. First, homemade mines generated economic and social impacts in affected rural regions because non-state armed groups restricted the mobility of their inhabitants and created family displacements [18]. Second, in addition to protecting illicit crops [14], home-made mines have been used by non-state armed groups to generate a strategy to consolidate their illegal operations, to increase their economic power and to change the political intention of the communities [18].

2.2. Home-made landmines in the internal conflict

The classification of anti-personnel landmines depends on the type of activation and the way they are buried, among other aspects. The International Campaign to Ban Landmines (ICBL 2014) classifies mines based on the type of activation: victim-activated or remotely activated. The second type includes a two-way radio that increases the amount of metal and can be easily detected by a conventional metal detector, while the first type can have low metal content and is the concern of this paper.

We classified home-made AP landmines according to container material, metal content, and type of activation. There are home-made AP landmines with low metal content and others that do not have metal; however, the containers can be plastic or glass and are shallow. The use of mines without metal parts increased false alarms in commercial detectors in the last decade. For this reason, a detector system must consider the landmine context and its physical characteristics.

3. Impacts, historical context and research

3.1. Impacts

The impacts of landmines on rural communities are many, but the most important is associated with social, economic, and environmental aspects. Impacts reflect changes in the way of life of their inhabitants, in their customs, in their fears, and modifications in the environment of the affected area (soil, flora, and fauna). However, the impact is mainly social because the affected community isolates itself from other nearby communities and generates an effect on the fears of the child population due to the presence of these devices, that is, there is a psychological affectation since the mines threaten their daily activities. Additionally, the economic impact is evidenced by the reduction of a community's capacity to carry out commercial exchanges with other rural populations and, consequently, a reduction in employment opportunities.

Certain characteristics of the soil surrounding the home-made AP landmine affect the performance of commercial detectors, such as the property for draining water. For example, Takahashi showed the effects of soil heterogeneity on the performance of soil penetration radars and metal detectors by recreating real conditions [19,20]. Therefore, just as soil affects the performance of detector systems, characteristics such as soil compaction can also be affected by buried landmines, as well as soil erosion. The impact generated by the neutralization of home-made AP landmines is one of the bases for building protocols for humanitarian demining in Colombia, especially the disposal of the different wastes generated during demining activities. Therefore, reproducing the physical properties of the soil surrounding a home-made AP landmine under laboratory conditions is quite a difficult task because the environmental conditions in the field and the texture of the soil affect its absorption and drainage of water.

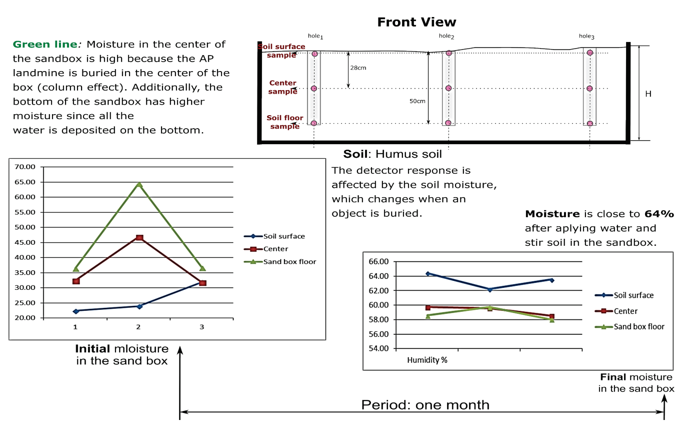


Figure 1. Front view of the sand box with humus soil, holes to collect soil samples, and soil moisture after to stir all soil content. A month before bringing the soil to the laboratory, it had a moisture level between 50% to 60%. This humus soil was brought from a village calles Zipaquirá, two hours from Bogotá.
Source: The Authors.

The environmental impact of landmines is associated with soil properties, such as its ability to drain water and heterogeneity because of change chemical and physical properties of soil. For this reason, laboratory tests included the effect of soil moisture and heterogeneity, while real-world tests generate information in each detector system that is very relevant to the physical characteristics of the home-made AP landmine and its location. Fig. 1 shows changes in soil moisture under laboratory conditions. This soil is from the región of Zipaquirá located near to Bogotá, with humus soil texture and water content between 50% and 60%.

Soil texture is one of the most important properties for demining activities. Every region anywhere in the world has soils with specific physical characteristics [21]. Basic soil particles such as sand, silt, and clay affect its storage and water passage, which alters the performance of instruments designed for home-made AP landmine detection, as it allows the precipitation of some minerals that can change their magnetic properties, affecting soil penetration radars and metal detectors.

Rainfall alters the magnetic properties of the soil in the affected regions [22] since its texture affects the accumulation of minerals. According to the United States Department of Agriculture (USDA), there are 12 basic soil textures divided into five subgroups (fine, moderately fine, coarse, moderately coarse, and medium).

In Colombia, 50% of antipersonnel landmine victims are within five departments (Antioquia, Meta, Caquetá, Norte de Santander and Nariño) [1], but two departments are being affected by other types of illegal armed groups (Norte de Santander and Meta) and three types of textures: clay, clay loam, and loam.

3.2. Historical Context

Education activities are risk reduction strategies designed to understand the risk of these threatening devices and reduce harm to the population. These educational programs illustrate and show the consequences to communities affected by landmines, and their effect is the reduction of accidents.

Another aspect of the historical situation of AP landmines is related to the use of technological tools for humanitarian demining, although if a country affected by these devices develops these tools, two aspects will develop its capacity to deal with this problem. First, there is no other way to understand and diminish the problem. Second, these technological tools built as prototypes can be considered and adapted to the problem, such as the difficulty in discriminating audio signals or the difficulty in recognizing visual signals because small metallic pieces buried in the soil are comparable to metallic components located in a home-made AP landmine.

History has shown that state support for research and development activities is important to design and build technological devices for demining. In 2000, Europe supported companies that were engaged in the construction of AP landmine detection systems through the creation of networks of excellence made up of companies and universities, which boosted company innovation, knowledge development, and increased the safety and efficiency of technology-based mine action programs. The results of many of these projects have one thing in common, the necessary inclusion of others in both the construction and actual testing of demining technologies. In 2002, Colombia determined the metal detector that best suited three rural regions (Niquia-Antioquia department, Larandia-Caquetá department, and the Military Base at Apiay-Meta department) based on tests on the metal detectors of three manufacturers that also participated in the networks of excellence formed in Europe. This study showed the existence of false alarms due to the type of soil, the type of object, and the environment surrounding the object under test; besides, in order to determine the metal detector that best fits Colombia's soils, as in other studies conducted in other countries affected by anti-personnel mines [23], we must take into account the application, as well as the type of soil in the affected region.

The cost required for the clearance of affected regions in Colombia has played a fundamental role in the search for strategies by the Colombian state. In Colombia, all groups or organizations engaged in demining activities obtain support funds from different sponsors because obtaining funds from international organizations is difficult because the internal conflict has not ended. Colombia is currently within an extension of time given by the United Nations to demine all of its affected regions [24], although in this extension period Colombia has evolved in the management of its mine action activities. Therefore, seeking funds and requesting extensions of time to carry out demining activities is part of the economic impacts generated by the demining activities needed to detect and deactivate home-made AP landmines.

Colombian Army deminers have mainly used metal detectors, although in some regions they have already started using dual detectors (Ground-penetrating radar + Metal detector) due to the presence of home-made landmines without metal components [25]. These home-made landmine components make it difficult to discriminate between buried objects using the audio signals or images generated by the detector system, as the deminer always has in mind that he will experience false alarms caused by the presence of the glass container. Radar-based detector systems have a high cost and are only used by deminers in regions affected by chemically activated mines [25]. For this reason, when a deminer uses a dual detector, he always operates it separately to observe the information generated by each detection system.

Both private and state-owned companies and universities (in Colombia and Europe) interested in generating knowledge for humanitarian demining, and with the support of Colciencias, have developed research projects to create tools for humanitarian demining [26]. Universities in Colombia such as Los Andes, Antioquia, Javeriana, and Nacional have carried out research projects to detect improvised explosive devices based on metal detectors and simulators [27], monostatic and polarimetric ground penetration radar [30], artificial vision systems [28], and nuclear quadrupole resonance [29].

3.3. Research and tools

The research and scientific documents generated by research groups focused on technologies for demining [31] and showing research gaps [11] are related to the detection and identification of anti-personnel mines based on exciting technological products, such as technological tools and signal processing techniques. However, they are for AP landmines other than home-made AP landmines.

Investigations involving home-made AP landmines must take into account three aspects: mines superficially buried in the ground, mines with only one detonator as the most unfavorable case for a metal detector, and mines with glass or plastic containers. However, we found other landmines such as deep-buried mines and located on the ground surface. The difference is the activation mechanism because the activation pressure can be reached by the weight of a vehicle or by traction cables located at distances greater than 15 cm.

With the experience of the demining teams in Colombia, this investigation was able to determine that the detection of mines with a size, shape, and structure different from those known as AP landmines requires other types of sensors and technology, probably technology that responds very well to both the size and the metallic content of some of its components. Fig. 2 shows a home-made AP landmine that members of the Colombian Army's demining team have encountered throughout their years of operation. Considering all types of mines can significantly change the design of the metal detector prototype of this project.

The detection of home-made AP landmines in Colombia must consider the physical properties of their components, the configuration used to locate them, both depth and relative position in groups of three, and algorithms for their detection and discrimination. These characteristics require adjusting the technology to obtain information from the buried object, such as the design of electronic systems that respond to its metallic component in the mine and algorithms to improve the detection and identification processes.

Figure 2. Mines in the mine museum at the Tolemaida Military Base.
Source: The Authors.

In the scientific literature, two authors show the two options mentioned, Tantum [32] and Kim [33]. Tantum showed signal processing in the time domain, which is the original domain of the metal detector used in its investigation, including the time interval with decaying signal values that provide better identification of the object near the search head. In Kim's paper, reducing the time interval with saturation in a metal detector by pulse induction increases the depth of detection by adding another circuit to the metal detector circuit to improve the penetration depth of the secondary magnetic field. These two aspects show that a metal detector without saturation in its response signal significantly increases the identification of the buried object and, besides, the cylindrical shape of the metallic object used by Tantum is similar to the shape of the detonator identified as the minimum metal in a home-made AP landmine.

3.3.1. Sensor-based tools for metal detectors

Signal processing techniques consider two basic operating principles in metal detectors: continuous wave and pulse induction [34]. We will focus on pulse induction metal detectors since 2000, because our prototype is a pulse induction detector. This type of detectors has raw signals with exponential decay, which is different at each metal detector because it depends on hardware designed by each manufacturer (see Fig. 3).

Tantum and Collins [32] acquired signals with the PSS-12 metal detector manufactured by Schiebel Corporation, which is a pulse induction metal detector with two concentric coils. One of these (external) is the transmitting coil, and the another one works as receiver. They conducted tests at the Joint Coordination Office of Unexploded Ordnance in Fort

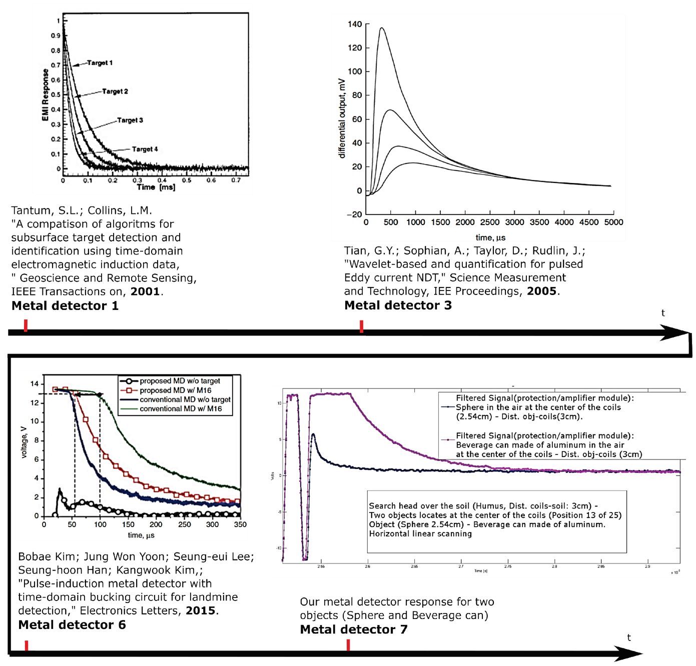


Figure 3. Signal shapes of some metal detectors developed in the last 15 years.
Source: The Authors.

Belvoir - Virginia, United States. The detector response was represented as a weighted sum of signals with exponential decay since the characteristics of the exponential decay depend on the composition and geometry of the buried metallic object. Besides, these exponential signals showed a decrease in magnitude related to the type of metal approaching the detector coil. Signal processing techniques considered the estimation of the exponential decay time interval to determine object identification using Bayesian principles. For this reason, this is a function-oriented algorithm.

Tian et al. [35] acquired signals by using a pulse induction metal detector. These signals allowed classifying and quantifying defects on the surface of metallic objects approaching the coils; besides, each signal shape has a time interval with a pulse. Authors used the peak value of this pulse and its location in the time axis for classifying the defects. The designed algorithm is oriented to type of object since the authors used a combination of Wavelet transform and principal component analysis (PCA) for extracting features and quantifying the depth of defects on the object surface.

Finally, Kim et al. [33] added a circuit known as Bucking Circuit to decrease the time interval with saturation and thus increase the depth of detection. They did not design algorithms for the signals acquired with the detector since the addition of the bucking circuit directly increases the penetration depth of the secondary magnetic field. Reducing the saturation time transforms the detector into a function-oriented system.

3.3.2. Ground Penetrating Radars

There are scientific papers showing that ground penetrating radar is a tool used in various applications [30,36-38,40], as well as a promising technology in the detection of landmines AP when we include detection algorithms [41-44]. Regardless of the application, Ground Penetrating Radars are designed under two operating principles [45,46], impulse or continuous wave. For this reason, there are different signal processing techniques, some of these are related to fundamentals [46-48]; besides, there are scientific papers dedicated to detection and discrimination of buried objects according to the domain, time, frequency, or time-frequency. We used a GPR based on Vector Network Analyzer in the frequency-domain called Stepped Frequency Continuous Wave (SFCW radar), which has some advantages over impulse radar such as accuracy, dynamic range, low noise, and frequency steps that can be randomly selected [45,49].

Some of the GPR designs reduce the acquisition time of their signals, while the algorithms are part of a set of tools that can be useful to different applications that seek the detection and identification of AP mines. The vast majority of these algorithms are applied to signal in time-domain leaving very few algorithms for signals in the frequency domain since in frequency-domain is impossible to visualize buried objects.

4. Methods and materials

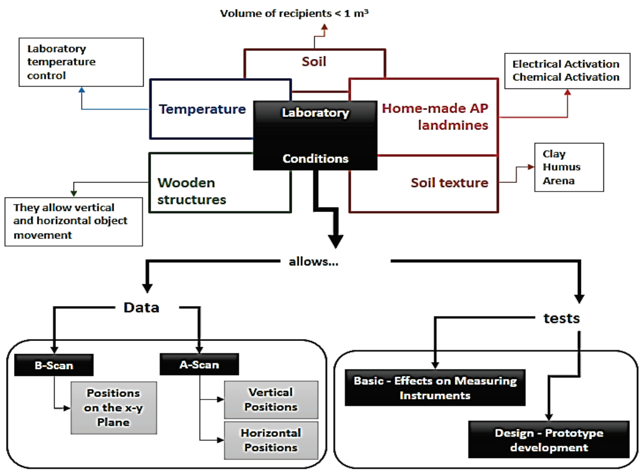
We designed two wooden structures, one for laboratory conditions and one for field tests, and several surrogate home-made landmines with electrical and chemical activation, in order to investigate the effect of the environmental conditions surrounding a home-made AP landmine, to determine the effect of the components of a home-made landmine on the performance of two detector systems, and to consider the effect of the measuring instrument.

Laboratory tests used soil samples in containers with a capacity of less than 1m3 and under temperature-controlled conditions. We conducted field tests on the test tracks of the Tolemaida Military Base with the support of the Colombian Army Demining Battalion. Because Tolemaida Military Base has four types of soils to test the performance of our detection systems (clay, loam, humus, and sand), the Field tests considered two of these textures (clay and humus). These textures correspond to the soils of the regions of Colombia currently affected by antipersonnel landmines, e.g., the Catatumbo Region; therefore, some manufacturers of commercial mine detectors have used soil samples to adjust their devices to the soil conditions in Colombia. The laboratory tests allowed us to adjust the design of the metal detector to the most unfavorable condition of a home-made AP landmine with electrical activation, as well as to adjust the operating parameters of the Ground Penetrating Radar, such as operating bandwidth and center frequency. Field tests allowed us to observe the performance of detector systems in the real environmental conditions affecting a landmine.

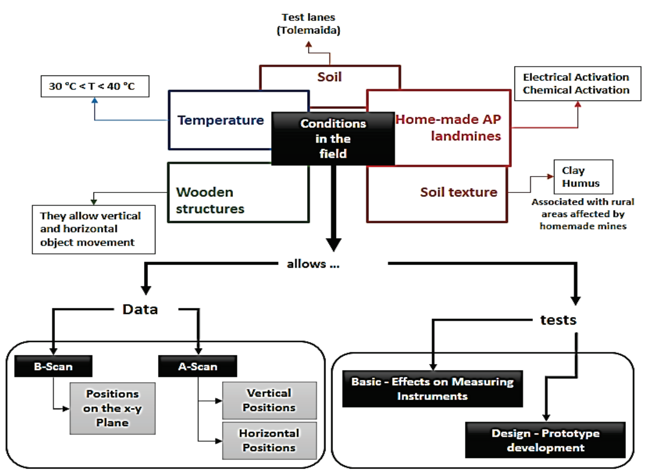
We used objects under test conditions with components that had similar characteristics to those found in affected regions. We built surrogate home-made landmines to simulate their effect on measuring instruments based on the experience of the Army Demining Battalion. Surrogate landmines have five characteristics of real home-made landmines: the size of the home-made mine; the electrical circuit used to activate the primary explosive; the fuse; the secondary explosive; and the material of its container. These characteristics created the same effect on detection systems, except for the secondary explosive, we used ammonium nitrate without motor oil to have a texture like ANFO (Ammonium Nitrate + Fuel Oil).

The home-made landmine with electrical activation has a detonator with its electrical power source located away from the mine, which is the most unfavorable condition for a metal detector. These components are connected by electrical wires that do not affect the response of the metal detector. Fig. 4 shows the characteristics of temperature, wood structures, soil texture, soil volume, and home-made landmines in laboratory and field tests.

In addition to the characteristics shown in Fig. 4, the domain of each signal produced by each of the sensor systems generates a system with two different signals, according to their domain (time or frequency domain). Although scientists usually take the signals to a common domain for further analysis, having different domains can be



a. Characteristics of laboratory conditions.



b. Characteristics of field tests.

Figure 4 Characteristics of temperature, wood structures, soil texture, soil volume, and home-made landmines in laboratory and field tests.
Source: The Authors.

an advantage for a feature extraction procedure based on algorithms designed for each domain and each sensor.

5. Implications for technology developments.

Some authors have shown that a single sensor as a simple tool to detect AP mines generates false alarms with objects that have minimal metal [50]. Identifying the amount of metal in an object buried in the soil is a difficult task because metal information confuses with soil information and other objects. For this reason, discriminating metal in a home-made AP landmine from metal in other buried objects involves adjusting the detector model to the amount of metal in the detonator, using the information collected to extract characteristics related to all the components of a home-made AP landmine, including soil, and constructing a strategy that combines these characteristics with the information collected with another detection system.

Landmine detection systems collect information from all components of the home-made AP landmine and other

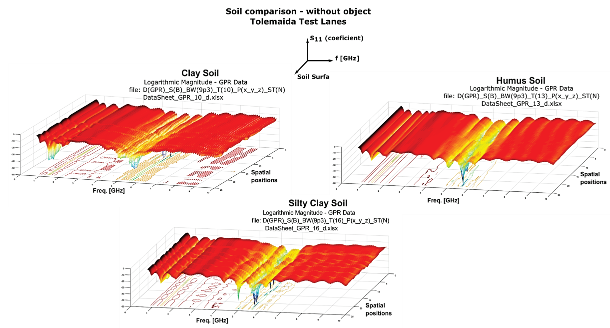


Figure 5. Image 1 shows images of three soils (Clay, Humus, and Silty clay) of the Tolemaida test lanes built with signals collected with a stepped-frequency GPR. These images show slight differences between 4 and 7 GHz.
Source: The Authors.

objects near the home-made AP landmine, including information from the surrounding environment; therefore, the soil is a component that affects any detection system and that, in a home-made AP landmine in Colombia, is not in direct contact with the detonator. For a metal detector, the soil generates an additive deviation on the collected signal when there are no other buried metal objects; therefore, the soil generates an effect similar to the effect of a DC component on the signal of a metal detector. For a GPR, the soil is the medium that affects the electromagnetic waves emitted by the antenna, without which, the collected signals would only have the effect of the existing connections between the antenna and the signal generator.

Fig. 5 shows images (logarithmic magnitude) of three soils (Clay, Humus, and Silty Clay) in the signals collected by a step frequency GPR, constructed as a surface with consecutive signals acquired at each of the spatial positions on three different tracks in Tolemaida. These images show small differences between 4 and 7 GHz, although there may be variability between consecutive signals.

These types of results show the bandwidth that algorithms designed to extract characteristics related to the mine and the soil must use. For a GPR, mine discrimination is the main problem in humanitarian demining activities, as the collected signals contain information of any object with sufficient dielectric contrast [46]. However, the variability between consecutively acquired signals (A-Scan) can be a useful tool to detect objects close to the surface and. Besides, if we use relatively high frequencies [51], the GPR will be more sensitive to the heterogeneity of the environment surrounding the home-made AP landmine. Therefore, soil heterogeneity can be attenuated by using relatively high-frequency signals and analyzing the variability between consecutive A-Scan signals.

Fig. 6 shows signals for three objects with different material (carbon steel sphere, aluminum can, N8 detonator), including a detonator inside a home-made landmine (lower set of signals); saturation as a value that could help differentiate the size of the detonator from other objects (aluminum can); and differences between consecutive positions of the metallic object within a time interval. Therefore, we cannot determine the size of the buried

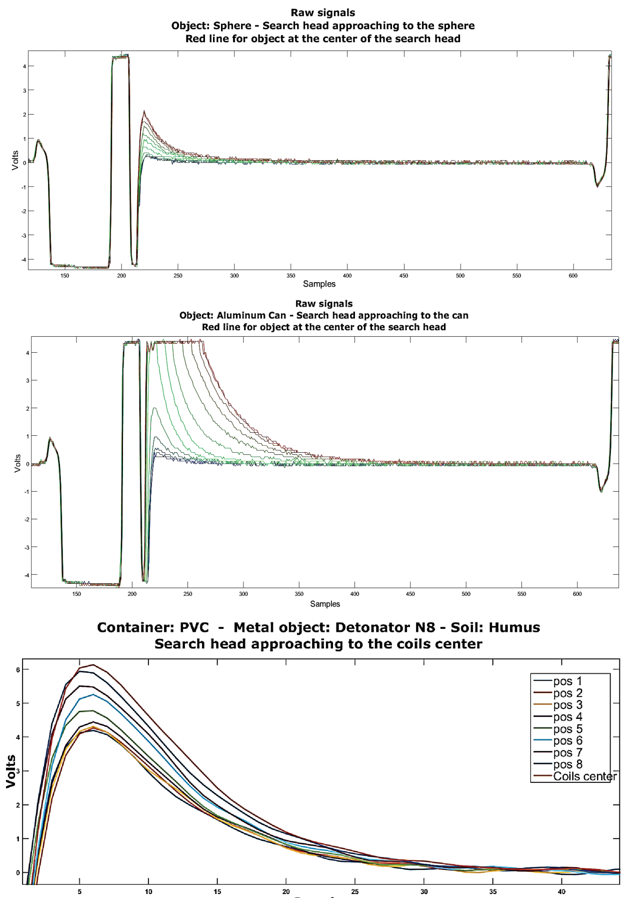


Figure 6. Metal Detector Prototype. Objects: Sphere, Aluminum Can, and Home-made landmine with detonator (Up to down). Las señales están dentro de medio período (periodo: 1 kHz, and 71⌠sg/sample)
Source: The Authors.

metallic object and discriminate against the home-made antipersonnel landmine from a sphere object, because the variations are very similar for these two cases.

The discrimination of a home-made AP landmine cannot depend on the characteristics extracted from the signals acquired with each of the detection systems. There is a detection, but discrimination can be achieved based on the combination of the results of various detection algorithms.

The peace agreement signed in 2016 is a point of reference for future humanitarian demining processes in Colombia since it generates changes in the way in which home-made antipersonnel landmines are buried and, in their components, because of the Colombian conflict is now a conflict over territory. For this reason, the analysis and observation of accidents caused by home-made AP landmines, after the signing of the agreement, are tools for the Colombian state to determine whether the components of home-made AP landmines changed and, above all, to use these changes to adjust existing technology or support new technological developments. The areas affected by landmines are smaller because these objects are in strategic points close to illicit crops, but the problem is unknown because we don´t know the type of improvised explosive device.

Due to changes in the internal conflict, the Colombian state must request a second extension to clear possible territories still affected by home-made AP landmines. The percentage of municipalities declared mine-free by 2019 is about 45% [1], but territories that remain affected, such as the Catatumbo region in the department of Norte de Santander, have problems that require more detailed analysis, although with IEDs that may have components different from those commonly used. Colombia does not have companies dedicated to the development of technologies for humanitarian demining to empower through research strategies, which creates additional difficulties when implementing useful technological innovations in field activities. However, there are two very different situations, reinforcing current technology and proposing a technological innovation.

According to the characteristics of our conflict, home-made AP landmines protect areas with illicit crops; for this reason, there has been great interest in using autonomous devices such as UAVs with sensors. These autonomous devices must operate with the existing vegetation around the illicit crops and generates two stages in the design of new technologies. First, adjust the model of the detector system and its sensors to the characteristics of the components of a home-made AP landmine. Second, adjust the design and algorithms to the environmental conditions of an area affected by home-made AP landmines.

6. Conclusions

The relevance of a method or technique in humanitarian demining may change due to the emergence of new conditions, e.g., in Colombia home-made AP landmines have different components than AP mine components used in other countries. Container material and the detonator are some of the components that produce false alarms in commercial detectors. For this reason, we propose to use geostatistical techniques in acquired signals with commonly used sensors, such as metal detectors and ground penetrating radars, to detect changes in soil characteristics around the mine; moreover, we also propose to analyze the shape of the pulse signal generated by the metal detector prototype related to the information contained in the secondary magnetic field, according to the induction process [34].

Prada [11] shows four technologies for mine casing detection based on electromagnetic methods, including metal detection. However, as home-made AP landmines have no metal container and minimal metal content, any metal detector we wish to use for home-made AP landmines must be adjusted to small metal objects including the size of the object. For this reason, the detection of the container of a home-made AP landmine must be supported by technologies that allow detecting changes of the medium such as GPR; in other words, the material of each component allows us to use a different technology to perform the detection and identification of home-made AP landmines.

Our metal detector system will be designed using one of the variables of the induction process, in which the variable of interest is the information contained in the secondary magnetic field, while the energy used to create the primary magnetic field remains constant during the time interval in which the induction process occurs. Therefore, we focused on extracting the most information from the secondary magnetic field without increasing the energy required to create the primary magnetic field.

Including a set of technologies developed through independent research projects is an option that must be considered in the future, especially, if we want to destroy this type of threatening artifacts from our regions and move knowledge forward. In the first place, the researchers of each project must adjust their technologies to the characteristics of the home-made AP landmines considering their components and other elements that affect them. For a second instance, the main objective is not to readjust each technology again but to adjust its parameters to extract as much information about the object and relationships between it and other elements that affect a sensor such as the soil. Each independent project will adjust all its parameters to obtain different performance conditions, with this the combination will guarantee that the information provided by each technology is directly related to home-made AP landmines used in the Colombian context. However, confidentiality conflicts can arise as in many cases these projects can be financed with different sponsors.

This paper showed that home-made AP landmines create a new problem to researchers interested in designing metal detector technologies since we explained that our current problem depends on physical characteristics of a mine, the findings of other researchers, and the historical context. The latter takes into account the activities carried out by the Colombian state to mitigate the problem and the fact that the use of these devices has been reported mainly through the media, as there is no truthful information about the moment in which its use began. These factors generate false alarms in commercial detectors. Therefore, researchers must take into account variables other than the depth of penetration of the magnetic field and the location of the metallic object, such as the duration and level of saturation, the detection of the secondary magnetic field, and coils configuration.

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