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Experimental assessment of the viability of using ground penetrating radar for metal wire-snare detection

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Abstract

Wildlife crime is an international issue with the illicit trade of flora and fauna estimated to be worth several billion dollars. In national parks, the problem can often be summarised as an arms race, with poachers trying to remain undetected by park rangers and other security personnel that are trying to protect the natural habitat and species from exploitation. Within this context, the detection of wire snares is a critical step. Not only can it reduce the number of animals caught by poachers but it can also help rangers develop better situation awareness and, in turn, improve patrolling strategies. To address the practical challenge of wire-snare detection across wide areas, this article examines the capacity of ground penetrating radar (GPR). Using two snares of small and medium sizes, the experiment confirmed the promising role of this technology, even if poachers attempt to conceal the snares underneath small tree branches and roots.

Keywords: Wildlife crime, Poaching, Snare, Radar, Detection

Introduction

Snare poaching

Estimated to be worth US$7–23 billion, the illicit trade of flora and fauna (trade of live and dead specimens and their products) is of growing international concern (Nellemann et al. 2014). Indeed, the trade and its associated activities affect not only *biodiversity* (e.g. animal population decline and possible extinctions) but also *health* (e.g. disease spreading, improper preparation of meat), *security* (e.g. terrorism financing through illicit trade in species) and the *economy* (e.g., costs associated to the damage and removal of natural capital) (Karesh et al. 2005; Pietschmann and Walker 2011; Warchol 2004).

To supply this illegal market, a variety of methods are employed that include poaching, i.e., 'the illegal taking of wildlife and wildlife resources' (Eliason 2003; Von Essen et al. 2014). Snare poaching, especially, is a relatively simple, inexpensive and effective technique that involves laying wire snares on the ground to capture animals (Becker et al. 2013; Fa and Brown 2009; Kelly 2013; Watson et al. 2013). In some instances snares will cause the animal's immediate death, but more often lead to starvation, dehydration, infection or attacks by other animals. The use of snares also results in high levels of by-catch that threaten a variety of species beyond the intended target (Garibaldi and Turner 2004).

Ranger patrols are currently considered to be one of the most effective 'on the ground' methods for poaching deterrence and detection (Hilborn et al. 2006; Kurland et al. 2017; Linkie et al. 2015). It has been argued, however, that they cannot be considered a perfect solution to the poaching problem (Barichievy et al. 2017). In a recent article, Duffy et al. (2019) also question what they call the militarisation of conservation, referring to the 'military origins and models that inform and guide (emerging anti-poaching) interventions'. Furthermore, ranger patrols have limited coverage in space and time. Analysis of ranger monitoring systems within the Greater Virunga Landscape (Africa), for example, has shown that the majority of patrol activity occurs within 3 km of ranger patrol posts, with only 23% of the park receiving sufficient patrolling for it to be an effective deterrent

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(Keane et al. 2011; Plumptre et al. 2014). Inconsistencies in patrolling levels within and around national parks is often attributed to a lack of resources, physical difficulty in accessing areas and/or political/personal safety issues. Despite these valid obstacles, variation in patrolling presence reduces the influence of guardianship, and provides poachers with areas of minimal monitoring that they can exploit. Moreover, it affects the ability of park managers to accurately estimate the prevalence of snares, which in turn affects the development of evidence-based prevention and enforcement strategies (Nyirenda and Chomba 2012; Wato et al. 2006).

To assist rangers and park managers in the detection and prevention of poaching activities, novel techniques and technologies are beginning to be explored (Fang et al. 2015; Hill et al. 2014; Kamminga et al. 2018). Amongst them, an idea is to use a radar system to detect airplanes, helicopters or unmanned aerial systems (UAS's) used by poachers (Ritchie et al. 2017). Another is to deploy a UAS that 'transmits sensor feed over a wireless network to a ground station' in order to achieve real-time detection of poachers or to monitor ongoing enforcement operations (Koh and Wich 2012).

Recent research piloting the use of UAS's and UAS images by Mulero-Pazmany et al. (2014) identified that it was possible to infer that and where poaching activities were taking place by detecting poachers in vehicles and monitoring animal movement using UAS images. However, they did not specifically assess whether such technology could be used for the identification of poaching paraphernalia such as snares, especially when covered by vegetation. To start addressing this gap, this article examines the potential use of radar systems for the remote detection of metal wire-snares.

Radar for snare detection

A wide range of sensors (optical cameras, hyperspectral cameras) exist that can potentially be deployed to detect and locate objects remotely. Amongst them, radio detection and ranging (RADAR) systems are commonly used when those are located in wide, dangerous or difficult-to-access areas. Radar systems can be operated in various environments—e.g., space (Pillai et al. 2008), air (Stimson et al. 1983), sea (Skolnik 2008), land (Skolnik 1980) or underground (Daniels 2007)—and various weather conditions (e.g., darkness, haze, fog, rain, or snow). However, we could not identify any previous study reporting the technical performance of radar systems specifically for this application. Neither could we find any in Kamminga et al. (2018)'s survey of poaching detection technology.

With monostatic radars, an electromagnetic wave is transmitted by an antenna. As it propagates through various media and encounters objects (e.g., metal, soil or stone), the wave is scattered in various directions. Part of the backscattered signal is then collected by the radar antenna and directed towards the receiver where the signal's amplitude and phase are analysed. Inverse techniques that involve comparing the received signal with the transmitted one are then applied to infer the material properties and location of the objects encountered by the wave (Skolnik 1980).

A type of ultra-wideband radar systems, ground penetrating radar (GPR) is commonly used to determine the geometric and geoelectric characteristics of the environment within which the waves propagate, including the scale and orientation of targets of interest. GPR, for example, is used to map subsurface structures such as the changing thickness and the extent of beds that relate to depositional settings. It is also capable of detecting concealed objects such as plastic landmines (Daniels 2007). Unlike conventional metal detectors that simply emit a sound when they are placed near a metal objects, GPR can generate high-quality radar images and potentially reveal targets as small as snares. For example, target detection of thin cylindrical metal wires were investigated by Briggs (2004) who explains how polarimetric radar systems can reveal metal wires (using different polarisations). Another interesting property of GPR is that target characteristics can sometimes be deduced by studying the electromagnetic waves at the receiver (Jol 2008). For our problem, it is therefore plausible that the electromagnetic signature of a metal wire-snare could be exploited to distinguish snares from other ground targets such as tree roots, debris or even decoys (e.g., drink cans) if the system was deployed and tactical displacement was taking place. Thin metal wire classification was demonstrated by Khodjet-Kesba et al. (2014). It is reported that the time domain profile of a thin metal wire is unique compared to other geometric targets such as sphere or cylinder. Metallic snares are expected to be good reflectors of radar signal, and their long round wires are likely to have an effect on GPR electromagnetic fields.

Research objectives

To assess the potential effectiveness of GPR systems in remotely detecting wire snares laid by poachers, we tested three hypotheses using a prototype system we developed. The first hypothesis relates to the detection of snares by GPR systems, the second to the discrimination from the type of clutter commonly found in the settings of operations. Finally, the third revisits the first two hypotheses under 'non-cooperative conditions,' where poachers might attempt to avoid detection by concealing the snares.

Hypothesis 1 The presence of metal wire-snares within the scene illuminated by a GPR will have a noticeable effect on the power level and signature of the backscattered signal.

Hypothesis 2 The signals backscattered by metal wire-snares and tree branches are sufficiently different to distinguish between them.

Hypothesis 3 Hypotheses 1 and 2 hold true even when metal wire-snares are concealed underneath trees branches and roots.

Methods

Design

To test the aforementioned hypotheses, we set up a GPR system, and manipulated the scene in its field of view (i.e., the experimental conditions) using different combinations of targets and clutter placed on the ground (Figs. 1 and 2). The radar antenna, pointing to the ground, was placed on a platform that could move between two tripods, approximatively 50 cm above the ground. For the measurement, the antenna was shifted horizontally along a straight line, by one centimetre steps, spanning a total cross-range distance of 1 m. At the end of each step, two measurements were made corresponding to

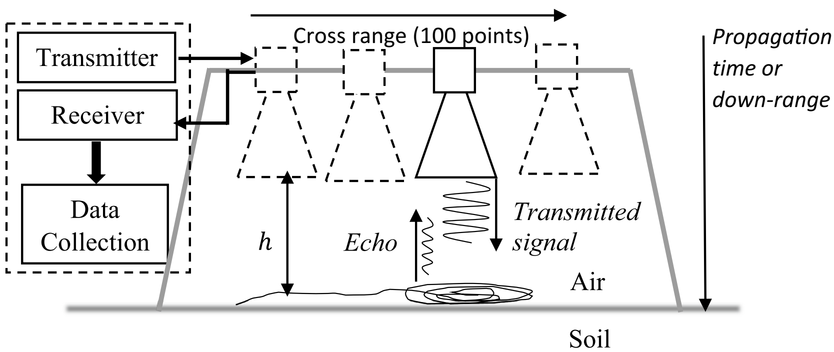

Fig. 1 Diagram representing the experimental setup (not to scale)

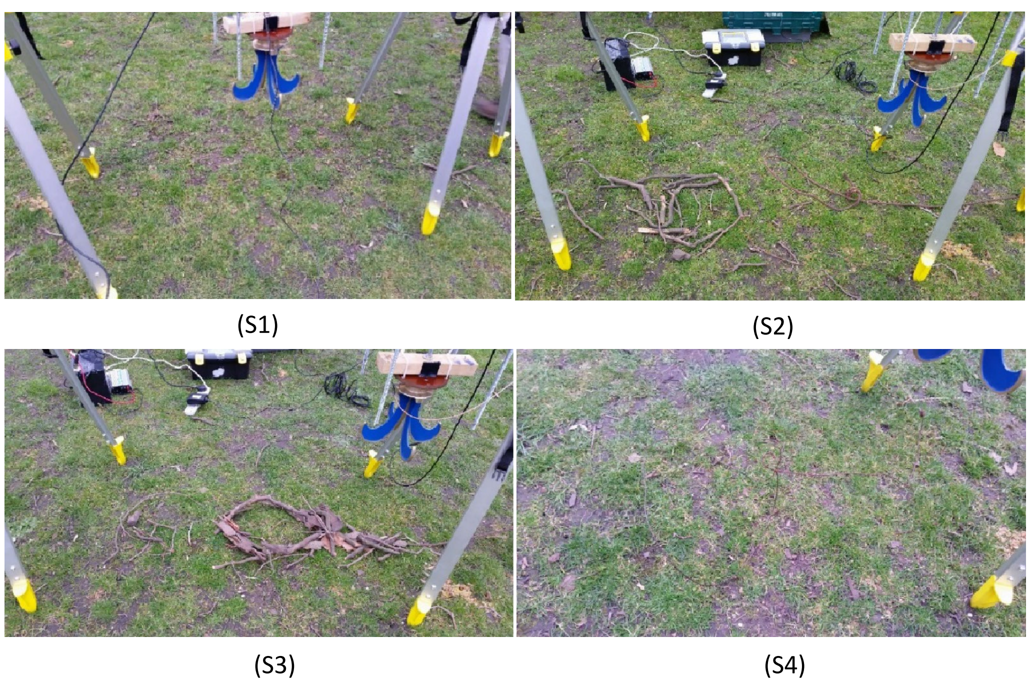

Fig. 2 Scenes: (S1) soil only, (S2) Type-A snare next to clutter, (S3) Type-A snare covered by clutter, (S4) Type-B snare

the following polarisations: horizontal polarisation (HH), and vertical polarisation (VV). The linear trajectory of the antenna allowed the illumination area to be progressively translated to create a two-dimensional scan known as a 'B-scan'. This technique is used to construct an image of the scene by integrating the 100 data points together (Daniels 2007).

The data collection protocol was repeated for four different scenes that correspond to different combinations of targets (no snare and two different types of snares) and clutter (with/without wood sticks) on a background composed of soil and short grass (Table 1). Two-dimensional images were processed and compared with each other.

As shown in Fig. 2, Scene 1 (S1) consisted of soil and grass only. In Scene 2 (S2), Type-A snare was laid on one half of the area and the other half was covered by tree branches and roots. The snare tail was laid flat and the snare's loop was raised above the ground slightly. In Scene 3 (S3), the same Type-A snare was visually obscured by covering it with small tree branches and roots. Finally, Scene 4 (S4) was created by laying the thinner Type-B snare on the group and slightly raising the loop.

For Hypothesis 1, the effect of the snares on the backscattered signal was determined by individually comparing the radar images of Scenes 2 and 4 (post-tests) with the image of Scene 1 (pre-test, soil only). For Hypothesis 2, the analysis was performed by analysing the patterns on the image of Scene 2 after removing the effect of the ground (Scene 1). For Hypothesis 3, the effects of covering the snare with wood sticks was determined by comparing the effects of the snare and clutter in Scene 3 and Scene 2 (comparison scene) on the backscattered signal. The individual effects of the snare and the clutter were then identified by analysing the image from Scene 3.

Table 1 The four scenes imaged by the GPR system

Scene	Target	Clutter (in addition to soil and grass)
S1	–	–
S2	Type-A snare (medium sized)	Wood sticks
S3	Type-A snare (medium sized) covered by wood sticks and roots	Wood sticks
S4	Type-B snare (small)	–

Apparatus

Two snares were used in this experiment that are displayed in Fig. 3 and described in Table 2. These snares were originally found by rangers in a protected area in Uganda, and are representative of the population of snares removed by rangers each month. Laid flat to the ground, leg hold snares have been found to be the most widely used by poachers (Becker et al. 2013; Noss 1998). The snares are of two different sizes: Type A for medium to large bodied animals such as waterbucks and buffaloes, and Type B for small bodied mammals such as warthogs and antelopes. Smaller and thinner diameter snares are often laid, slightly raised above the ground to aim for the head of the smaller animals.

Measurement system

The GPR system used in this study is a vector network analyser (VNA) based radar that has been developed by one of the authors (Amiri 2016). Originally designed for landmine detection, the system consists of three parts: radar system, antenna and platform. The radar system

Table 2 Characteristics of the wire snares used in the study

Snare provenance	Protected area in Uganda
Snare material	Metal
Snare type	Leg hold wire snares
Snare wire diameter	Type A (8 mm), Type B (2.5 mm)

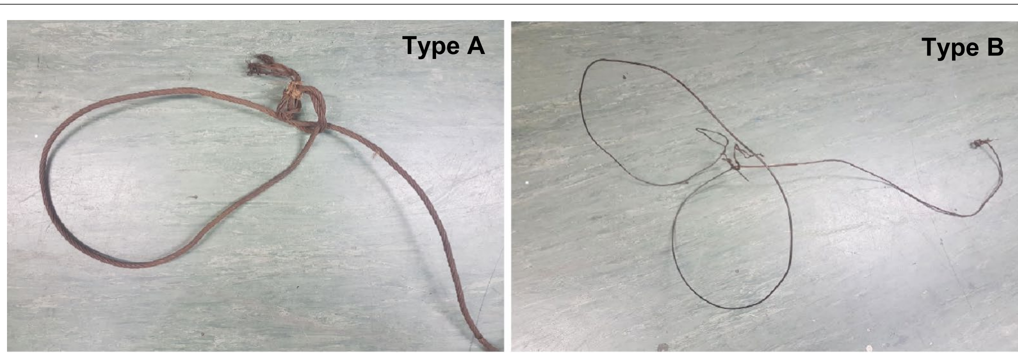

Fig. 3 The two wire snares used in the study

comprises a unit that generates and sends signals to the antenna, or receives signals from the antenna. The system is connected and controlled by a laptop where all the data is captured and stored.

The radar is an ultra-wideband (UWB), stepped frequency continuous wave (SFCW) radar that operates in the frequency domain. This type of radar captures both the amplitude and the phase of the return signals. The specifications are summarised in Table 3.

The antenna is a Quad-Ridged horn antenna. The signal from the antenna forms a conical radiation pattern that propagates outward. Its beamwidth varies as a function of frequency, from 90° to 30°. When pointing directly toward the ground, at a height of about 50 cm, the antenna illuminates 0.8 m^2 surface on the ground. Because the radar target can change the polarization of the transmitted wave (Sinclair 1948; Kennaugh 1952), targets can also be distinguished from others by considering the polarisation, as explained above. In the study, the antenna could operate in two polarisations: vertical and horizontal. The main parameters of the antenna and its setup are summarised in Table 4.

For the purpose of our experiment, the VNA and the antenna were mounted on a linear positioning system that consists of a small cart on a 140 cm rail. The rail was mounted on two tripods and raised at a height of 130 cm above the ground. Distance from the antenna to the ground was set at 50 cm. The GPR system is shown in Fig. 4.

Fig. 4 Measurement setup with the radar (top) and the antenna (bottom) between the two tripods, Tavistock Square, London (UK)

Results

When GPR are used to image buried or subsurface targets, the result is commonly in the form of a *radargram* such as those presented in Fig. 5. Each two-dimensional plot represents the signal strength for different time delays. Each time bin (y axis) corresponds to a given propagation time (i.e., the time it takes for the radar signal to travel to a scattering point and back). The brighter the pixel, the greater the strength of the signal backscattered from the corresponding point. Although this plot does not represent the geometrical representations of the target (because the wavelength is too high in comparison with the physical dimensions of the target), it provides a profile and a signature that is related to the target's size and shape.

The raw data recorded from the radar is in the form of amplitude and phase reflected from the target. In order to reconstruct an image, the raw data were first used to construct a complex signal. The inverse fast Fourier transform (IFFT) of this signal was then taken to translate into time domain. In this experiment the data was captured in two types of scans: A-scan where a single radar signal is recorded from the antenna at a given fixed position above the ground; and B-scan, where a set of A-scan traces recorded by moving the radar system on a linear trajectory are then integrated together to construct a two-dimensional image.

Table 3 Specifications of the radar system

Radar type	SFCW
Frequency of operation	800 MHz to 8 GHz
Number of samples	635
Frequency step	11 MHz
Transmitted power	+12 dBm (0.012 W)

Table 4 Antenna parameters and setup

Antenna configuration	Monostatic (i.e. single antenna)
Frequency of operation	800 MHz to 8 GHz
Polarisation	Vertical (V) and horizontal (H)

Scene 1: Reference measurements (pre-test)

Before any snares were introduced in the scene, the ground was first illuminated to provide a set of reference measurements (pre-test). The radargram (time bin vs cross range vs intensity plot) in Fig. 5 shows a strong reflection (bright horizontal line) in bins 36–38. This is due to the change in the electrical characteristics at the air–soil interface. Once the radar waves enter the soil, their velocity decreases. Together, the velocity encountered and electrical properties of the soil can provide information about the characteristics of the soil. This includes disturbance in the soil, attenuation, water content and so on. The disturbance in the soil is of particular interest here, since it produces a distinct radar

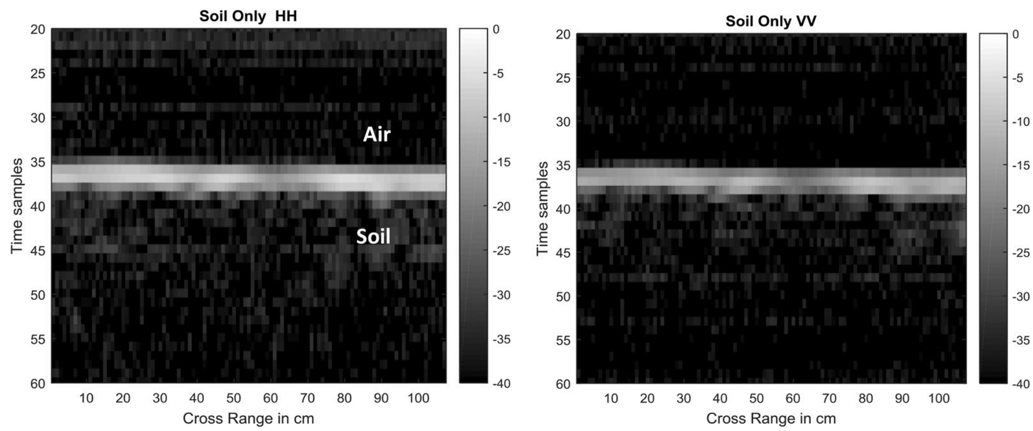

Fig. 5 Scene 1—soil only in horizontal polarisation (left) and vertical polarisation (right)

signature which can be examined to ascertain whether any targets are present on/in the soil. In Fig. 5, the soil interface appears uniformly distributed, for both polarisations (HH and VV).

Scene 2: Type-A snare next to clutter (post-test)

In Fig. 6, the tail and loop of the snare are clearly visible, and marked by arrows. If the target geometry aligns with the polarisation of the radar signal, it yields a strong reflection. With HH polarisation (left), the stronger scattering points are the tail and the knot of the snare. In contrast, with the VV polarisation the dominant one is the loop of the snare. The tree branches are also visible on the right hand side of the radargram, but the return is not as strong as for the snare.

Scene 3: Type-A snare concealed by clutter (post-test)

In Fig. 7, the snare is covered by tree branches and laid flat on the soil. Despite the visual cover, the signature from the snare can still be detected on both radargrams. The distance between the two scattering points (marked by arrows) is approximatively 40 cm which corresponds to the dimension of the major axis of the snare when it was laid on the soil.

Scene 4: Type-B snare only (post-test)

Despite a relatively small cross section, the 2.5 mm Type-B snare can still be detected in both polarisation (Fig. 8). On the HH radargram, the profile of the snare as a whole can be clearly observed. When using the VV radargram, we can notice two peaks that appear to correspond to the two loops of the snare: a large loop and a smaller one used to tighten it when the animal moves its leg. This very distinctive feature on the signature can be used to

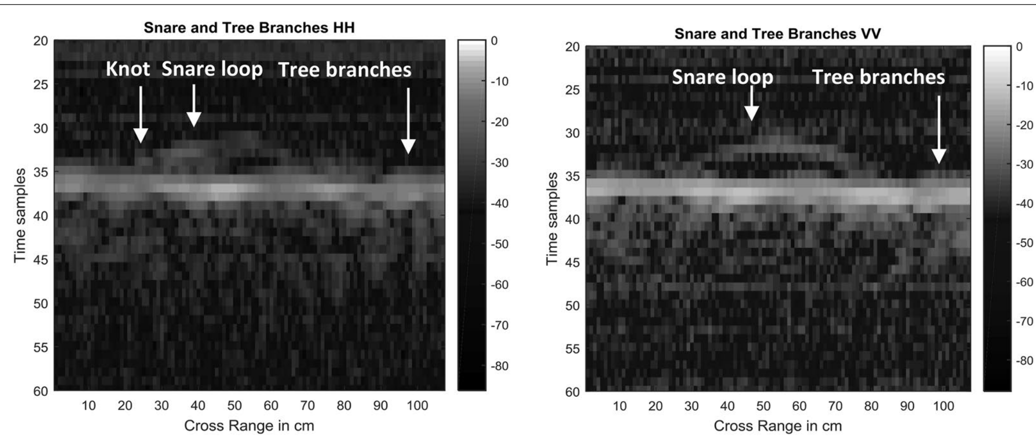

Fig. 6 Scene 2—Type-A snare next to clutter—horizontal polarisation (left) and Vertical polarisation (right)

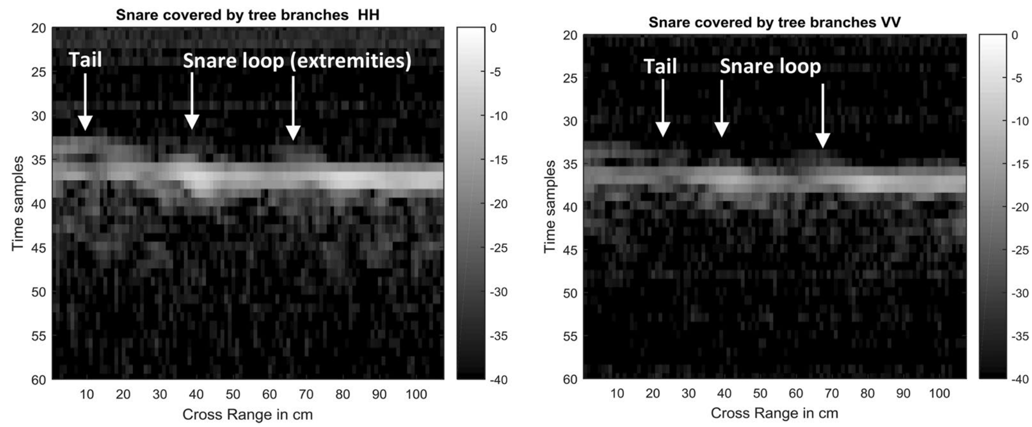

Fig. 7 Scene 3—Type-A snare covered by clutter in horizontal polarisation (left) and vertical polarisation (right)

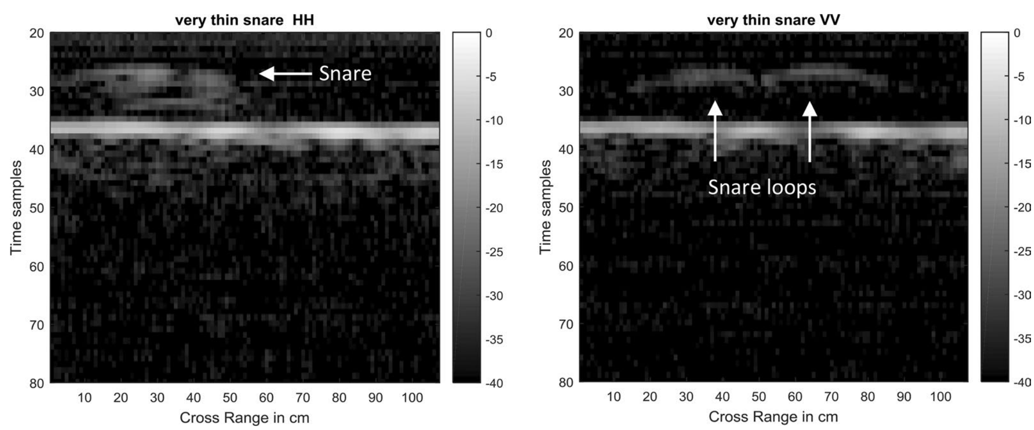

Fig. 8 Scene 4—Type B snare in horizontal polarisation (left) and vertical polarisation (right)

discriminate between snares and other objects present in the environment.

Discussion

Can GPR be used for snare detection?

In this study, we have tested three hypotheses related to the potential use of GPR systems for detecting metal wire-snares used by poachers. First, the results of the experiment support Hypothesis 1. As shown by Figs. 6 and 8, both types of metal wire-snares (medium and thin diameters) can be detected using the GPR system used in this study. Second, the results also support Hypothesis 2, as the radar signatures of the snares (both Types A and B) are stronger than that of the tree branches and roots. In addition, we have shown that the two loops create discriminatory features on the radargrams that can be used to distinguish snares from other objects in the environment (Fig. 8). Finally, Hypothesis 3 is also supported as the metal wire-snare could still be detected on the radargrams when it was concealed by tree branches.

The results show that the loop of a snare introduces an arc-shape in a 2D plane. This suggests that it should be possible to reconstruct a more realistic profile of the snares by moving the radar along the x–y plane—note: z is denoted as depth axis.

Polarisation information and the use of both high and low frequencies in radar systems can allow enhanced detection. The signal can penetrate deeper and propagate through dense materials such as rocks and foliage. The polarisation information can provide information that are specific to metal-like structures, which can help distinguish metallic man-made structures from others. Having demonstrated the capability of our prototype system for target detection and recognition, we argue that the remote sensing capability of GPR technology could be very useful to achieve semi-automated snare detection. In comparison with conventional metal detectors that have an effective range of about 1 m and limited field of view, GPR would be especially useful to distinguish snares from metallic debris and decoys in certain environments.

The proposed system can also be adapted to various environments by replacing some of the components in the hardware. These are readily available off-the-shelf components that are rated for specific ranges of typical radar parameters such as, frequency, polarisation, power, noise figure, etc.

Different nature reserves may include various types of ground surfaces and may be populated with debris, for instances foliage, rocks and tree roots. The radar signal can propagate through all of these materials but one has to take into account the capability of the radar hardware to successfully detect targets in these scenarios. Foliage penetration often requires low-frequency range in the UHF and VHF band. A denser and debris packed environment tend to depolarise radar signals, so a dual or circular polarised antenna is more suited for this. Once the back-end radar system is in place, the front end modular components can be chosen depending on where the system is deployed.

The proposed GPR system also has an advantage of having low power consumption compared to other types of radar systems. This allows the system to be driven from small and lightweight power sources, which is an important element to consider for UAS applications. Mounted on a UAS, a GPR system could, in principle, achieve snare detection over vast areas of difficult terrain where rangers would not normally venture. The application of UAS's to the patrolling of national parks could greatly reduce the time and resource pressures on the rangers and park managers, and provide a new source of data from which analysis of a variety of conservation and biological processes could be based. UASs, in particular, could offer a flexible, portable and low cost (in comparison to salaried individuals) method for monitoring areas where there are physical or political obstructions and are beginning to be explored as an additional tool in the arsenal against environmental crime for conservation (Jonsson et al. 1980; Cook 2007; Anderson and Gaston 2013).

Limitations

This experimental field-test has a number of limitations that should be considered before drawing any conclusions from the results. First, the experiment was conducted in London (UK) where it was difficult to fully appreciate the constraints under which rangers operate. Further work should be conducted to better understand the requirements of rangers and relevant third parties (Borrion et al. 2019). Second, the results may not be as convincing in very different environmental conditions. On the day when the data were collected, the soil was neither too dry nor too wet, and with short grass. However, the contrast between snares and background may not be as high with greater moisture level and longer grass. The presence of snakes on the ground may cause a number of false alarms too due to their geometric and electrical characteristics. Third, the position of the snares and the altitude at which the measurements would be made in real operations are other important aspects to consider. In the experiment, the snares were laid flat on the ground. However, snares may also be found in other positions (e.g., vertical). In addition, the antenna was kept relatively close to the snares (50 cm). In real operational settings, this is unlikely to be feasible, for example if the fly path is obstructed by the vegetation or if the UAS is at risk of theft or damage by poachers. In practice, this means more innovative processing techniques may need to be developed to obtain images of sufficient quality without increasing the payload, the power or the size/number of antennas. Further work is currently being conducted to increase the performance of the radar system for this application.

With improved hardware and more advanced signal processing, this technology could be applied to reserves that have different environmental backcloths. Environmental conditions such as ground material have an effect on the radar signal. The interface between the ground material and the system (i.e. the antenna) is designed to remove this effect. Different antennas can be designed to suit a variety of ground material; and with a modular system, they could be slotted in when needed. As an example, a single antenna that can operate in multiple environments is described by Amiri (2016). In that work, a UWB horn antenna is proposed that can operate in multiple frequency band and multiple polarisations. By controlling the polarisation, frequency of operation and reduced interference effect of the ground, the antenna is proposed to operate in various environments including, for example, dense materials, rocky and pebbled ground and foliage.

Conclusions

The results of the field test suggest ground penetrating radar systems have a promising role to play in the detection of metal wire-snares used by poachers, and in distinguishing them from tree branches, roots and debris that could be found along animal trails. In particular it has shown that the polarisation information could greatly help identify signatures from the loop, knot and tail. If tactical displacement takes place after the system is deployed, the radar could become especially useful to discriminate snares from metallic decoys. Finally, it suggests that metal wire-snares could still be detected even when they are concealed using small tree branches and roots. Before such technology can be validated, comparative tests should be performed with metal detectors and optical sensors, for example.

Abbreviations
GPR: ground penetrating radar; HH: horizontal polarisation; IFFT: inverse fast Fourier transform; RADAR: radio detection and ranging; SFCW: stepped frequency continuous wave; UAS: unmanned aerial system; UWB: ultra-wideband; VNA: vector network analyser; VV: vertical polarisation.

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Authors' contributions
All authors contributed to the following sections: "Introduction", "Discussion" and "Conclusions". The experiment was conducted by AA and HB, who also wrote "Methods" and "Results" sections. The snares were supplied by AML. All authors read and approved the final manuscript.

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Competing interests
The authors declare they have no competing interests.

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