SUBTERRANEAN WARFARE — USING ARTIFICIAL NEURAL NETWORKS AS AN ADD-ON TO GEOPHYSICS DETECTION TOOLS

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Overview

Widely exposed to the public since the hostilities in the Gaza strip, tunnel warfare is very much entrenched in the 21st century as a contemporary military tactic. State actors as much as violent extremist organisations and transnational criminal organisations are using subterranean complexes. Examples abound throughout the world how they are used to hide military assets, launch rocket attacks and facilitate illicit activities, such as smuggling weapons, drugs, people and other contraband.

The growing use of subterranean complexes by military and asymmetrical forces to obtain tactical and operational advantage is making the likelihood of encountering such structures on future battlefields inevitable.

As stated by Atai Selach “subterranean warfare is an evolving dimension of warfare and not a standalone obstacle, but an entire world of multidimensional warfare. The subterranean medium is already a part of all modes of battle and belligerence”.

Subterranean warfare is as old as war itself, and was often used in ancient and medieval times to enter into or destroy enemy fortifications (mines and countermines) and defeat sieges. In modern times, subterranean warfare has been used to conceal military capacities, secret programmes (e.g. Iran) and troops movements (e.g. Vietnam and North-Korea). It is largely used in asymmetric war tactics and insurgencies – the Taliban in Afghanistan, Hamas in Gaza, Hezbollah in Lebanon, and the FARC in Columbia.

India is experiencing the threats of cross-border tunnels, particularly in Kashmir.

Removed from the priorities of modern armies during the late 20th century, since mobility was one of the key words of military strategy, subterranean warfare is back in the forefront of military concerns. So it is no surprise that the U.S. Army just issued a warning about tunnel warfare as part of a new effort to acquire specialised high-tech robotics, communications gear and other equipment.

In subterranean warfare, the detection of the subterranean complex is the first component of any countermeasures. In this article we will briefly look at the history of subterranean warfare and describe how subterranean threats are detected. We will suggest an additional method to uncover subterranean activities, not by replacing current technologies, but by adding a supra analytic tool – namely an artificial neural network – to be connected to geophysics sensors as well as being fed inputs from many other sources.

Detection of Subterranean Complexes

Overview

During ancient times, several schemes were used to detect tunnels being dug, some of them quite “colourful” such as watching for vibrations on bowls of water or tiny bells attached to a stretched bit of parchment diaphragm. Surrounding the area to be protected with a moat full of water was then seen as the best protection against mining.

World War I saw an increase in the use of mines and countermines, and the usage of geophones – an in-earth acoustic surveillance device consisting of a stethoscope attached to two discs with mica membranes holding mercury which allowed sounds to be amplified.

Subterranean complexes should theoretically be easily identifiable targets since they present a large contrast in properties between an air-filled void and the surrounding geologic material having a much different density and

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1 In this article, we are defining subterranean complexes as tunnels, underground facilities, and urban and natural cavities. However, we will not further classify these complexes according to their specific attributes, such as their physical characteristics, functions, infrastructure, threat level and accessibility.
4 Such as the siege of Constantinople in 1453 or Kazan in 1552.
5 Modern geophones would sit in between accelerometers and seismometers.
velocity (air has a density of 1.225 kg/m³, most surrounding subterranean medium would have a density approximately one thousand times higher). It should then be quite straightforward to detect subterranean complexes: ping mechanical or electromechanical waves and the distortions to the returns and the waves’ propagations could help find a cavity. But, we are dealing with geophysics and a variety of parameters, many types of soil and geological formations (e.g. water tables, cracks, etc.)

Detection technologies are numerous, but the ones used the most evolve around detecting (i) acoustic activity, (ii) seismic activity, (iii) density anomalies, and (iv) magnetic anomalies. Let’s briefly examine some of them.

**Imaging Technology**

Imagery intelligence (IMINT) brings critical data to the detection of subterranean complexes. Airborne sensors are capable of localising entrances of tunnels, as these often emit temperature fluctuations that can be sensed. Fluctuating colours, captured by hyperspectral cameras, indicate disturbed top soil, a possible sign of a tunnel being excavated. Multi-spectrum imagery are able to spot surface anomalies that could indicate subterranean vents, intakes or portals. Special cameras can sense chemicals releases from ventilation system exhaust.

US satellites – equipped with special high resolution infrared detection technology – can identify changes in terrain density, which may lead to the discovery of tunnels.

**Acoustic Sensors**

In short, acoustic sensors are a huge improvement to holding one’s ear to the ground. In their simplest form, acoustic sensors are microphones set on the ground and connected to advanced processors. Another commonly used set-up is to dig pits and put microphones inside.

**Raytheon BBN**

A system developed by Raytheon BBN, called “Border Tunnelling Activity Detection System”, has been deployed in the US on the border with Mexico. No much is said about the system for which Raytheon filed a patent under the reference US20110169638 A1. When looking at such patent, one may learn that BTADS is a system that “employs vibration sensor pairs, with each sensor pair having a shallow sensor and a deep sensor. Outputs of the sensors of a pair are processed together and events are detected based on the relative values detected by the sensors of the pair.”

**OptaSense**

OptaSense, a QinetiQ-owned company, has developed a technology (based on distributed acoustic sensing) that can turn any existing fibre-optic cable into a highly sensitive real-time microphone. With millions of miles of fibre optic cable underground and undersea around the world, the ability to turn this into a “listening” device has enormous potential in terms of discovering subterranean complexes. Sensitive enough to detect footsteps, vehicles, digging, or even a helicopter passing overhead, the technology is already being used as a means of advanced security monitoring for perimeters and assets.

**SureWave Technology**

SureWave Technology’s Tunnelling Alert System (TAS2) claims to detect intruders tunnelling up to a depth of 1,000 feet underground, and across a surface distance of up to 1,500 feet from the system’s sensors. It involves the use of highly sensitive ground sensors which relay the micro-seismic signals to a CPU using an advanced software. The company stresses that the ability of their software to filter out the majority of extraneous seismic signals which are of no importance is a key to their performance.

**Seismic Sensors**

Seismic sensors are devices used to measure seismic vibrations by converting ground motion into a measurable electronic signal. As the signal is analogue in nature, sensors must be linked to a data acquisition unit to convert its output into a digital format that can be read by computers.

Methods using diffracted P-waves and backscattered surface waves have produced promising results in identifying subterranean anomalous events, since it is known that seismic diffractions can occur as a result of subsurface objects acting as secondary energy radiation point.

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6 Sloan, Steven et al. “Tunnel detection using near-surface seismic methods” Geophysical Society of Houston, November 2013
8 Sloan, Steven et al. “Tunnel detection using near-surface seismic methods” Geophysical Society of Houston, November 2013
The method is based on geophones that are placed at a certain depth into the ground and which measure energy waves in the earth. When an activity is registered in the protected area, the seismic sensors produce a signal which is processed in real time through an advanced algorithm, identifying which type of activity has been registered, digging, walking, vehicle, etc. The underground sensors can be installed at varying depths and distances from each other. Each sensor has an adjustable detection range that is usually overlapped by several units for increased reliability.

Technion

Using BOTDR (Brillouin optical time-domain reflectometry) technology, engineers at Technion, the Israel institute of technology, have built a virtual underground fence. The principle involved is similar to reflection seismology, except that electromagnetic energy is used instead of acoustic energy. According to the developers: “Recent advances in distributed strain measurements using fibre optics enable the development of smart, underground security fences capable of identifying and locating tunnel excavations. … By measuring the developed strains in the soil with sensitive equipment, one can find the tunnel’s location.”

Ground-Penetrating Radars (GPRs)

Ground-penetrating radars (GPR) are applications-oriented geophysical equipment using radar pulses to map the subterranean surface. The GPR signals will be reflected every time their velocity changes, when hitting changes in soil type, buried objects, underground structures or voids. GPRs can be surface-operated – by hand or on a vehicle, placed in boreholes, or located in aircrafts and satellites.

Other Technologies

Some new technologies have been tested such as Electrical Resistivity Tomography (ERT), an earth resistance technique for imaging sub-surface structures from electrical resistivity measurements made at the surface, or by electrodes in one or more boreholes. Other researches involve microgravity – the measurement of minute changes in Earth's gravitational field caused by cavities in the ground, or the use of technologies using cosmic rays and electrodes.

Limitations of Geophysics Solutions

Regardless of the technologies used, factors including geologic material and its complexity (e.g. clutter confusing the sensors), depth and ambient/background noises such as rain, wind, underground utilities (e.g. water pipes and sewers) and transport systems, will always render the detection extremely challenging.

Tunnels differ greatly in dimension and depth, which also complicates detection through high-tech methods. As an example, ground penetrating radars return meagre results in urban surroundings or in moist, clay-rich soils.

David Masters, Senior Adviser at the US Department of Homeland Security, declared that the solution is to first build computer simulations of the actual geology one wants to probe, then to build models of how various sensors, seismic or ground-penetrating radar perform there.

A quote from a report “Hamas Underground Warfare” produced by the Israeli-based Begin Sadat Security Academy illustrates the problematic: “As yet, no reliable technology has been developed that can cover a wide area and see a man-sized tunnel to a depth of more than a few meters underground”.

Other experts, like Paul Bauman from Canada, caution that there is not a single foolproof solution to discover tunnels and that a combination of several techniques is required.

Furthermore, human elements and their expertise are essential. To detect subterranean complexes, the defence community must penetrate into the unfamiliar world of geophysics, this is one of the reasons why discovery teams should always include terrain professionals, whether geologists or physicists.

8 Roston, Aram. “DHS tries to find tunnels below the surface” Defense News, 13 March 2013
10 Shamah, David. “Tunnel detection tech can work for Israel, says expert” The Times of Israel, 23 July 2014
Using Artificial Neural Networks

**Definition**

An artificial neural network (ANN) is a “connectionist” mathematical or computational, adaptive paradigm, based on brain neural networks.

ANN is a form of artificial intelligence (AI) technology made up of a collection of interconnected artificial neurons, which are able to learn complex nonlinear I/O relationships using sequential training procedures, and adapt themselves to the data\(^ {12}\). During the learning stage, ANN changes its structure based on internal and external information it processes.

ANNs implement algorithms, which try to equal neurologically-connected processes and achievements, such as making generalisations from comparable conditions. We are using the ANN for pattern recognition – currently, its most common application – to which we will add anomaly detection (i.e. firing a specific output when some occurrence does not fit the pattern)\(^ {13}\). ANNs are good at discovering associations or regularities within a large set of much diversified inputs, or where the relationships are unclearly understood or hard to define with conventional methods\(^ {14}\). One of the major advantages of ANNs is their apparently low dependence on domain-specific knowledge.

**Approaching the Problem with ANN**

The first premise of our approach is that every action leaves a trace, even an infinitesimal one – as the French scientist Lavoisier declared “nothing is lost, nothing is created, everything is transformed”. Our second premise is that (almost) everything can be observed with modern technology. The level of sophistication of current observation sensors and tools (e.g. image, audio, cyber, etc.) is such that there is hardly a place on Earth where something may remain undetected for long.

However, random detection of separate phenomena are not often connected, thus no “bigger picture” may emerge from what could be or would be separate signatures of the same occurrence. It is therefore rational to hypothesise that fusing an array of observations into a multi-modal supra system may display an image which is not perceived from seemingly unconnected micro-events.

So let’s assume that we are systematically collecting and entering into an ANN what we are calling in this article “trivial observations” and refer to as TO. Trivial observations are observations of the “everyday life” and include elements such as images of urban structures at different times of the day, frequency of garbage collections, crops being harvested late or early in the season, flocks of birds not returning to their usual spot, etc.

To assemble these TO, we are hypothetically using all available data gathering systems, including tools from the electronic support segment\(^ {15}\) of Electronic Warfare, to which we are adding open-source imagery and human intelligence (HUMINT). All TO, some of them after having been subject to pre-processing, will then be entered into and processed by the ANN. When an array of TO differs from known or estimated standards, the ANN will automatically recognize patterns and detect anomalies (in our case, subterranean activities).

**Structure**

We are suggesting using a multilayer perceptron (MLP), which is a feedforward ANN (i.e. data is propagated from the inputs to the outputs). This ANN will use a backpropagation supervised learning technique (discriminant analysis). The activation function will be a nonlinear continuous function (sigmoid). We are assuming the availability of large scale computational resources.

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\(^{13}\) Bilet, Jerome “Artificial Neural Networks, Pattern Recognition and Unstructured Data”, White Paper 2007


\(^{15}\) Such as measurement and signature intelligence (MASINT), signal intelligence (SIGINT) – electronic intelligence (ELINT) and communications intelligence (COMINT) – and imagery intelligence (IMINT).
Data Acquisition – Inputs

Some examples of TO are listed below (non-exhaustive list):

<table>
<thead>
<tr>
<th>x</th>
<th>Inputs</th>
<th>Categories</th>
<th>Examples of Discriminants</th>
<th>Examples of Queries</th>
</tr>
</thead>
<tbody>
<tr>
<td>x1</td>
<td>Area</td>
<td>Isolated, farming, industrial, urban, residential, business</td>
<td></td>
<td></td>
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<tr>
<td>x2</td>
<td>Soil – Geology</td>
<td>Physical properties, composition, water</td>
<td></td>
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<tr>
<td>x3</td>
<td>Soil – Appearance</td>
<td>Presence of disturbed soil Soil of a different colour than the surrounding soil Dirt scattered within proximity of residence, businesses or water source</td>
<td></td>
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<tr>
<td>x4</td>
<td>Air</td>
<td>Clear, smoke, dust, pollution Is the air quality slightly fluctuating</td>
<td></td>
<td></td>
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<tr>
<td>x5</td>
<td>Roads</td>
<td>Roads, trails, paths, destination, purpose Do all the roads have a purpose Are roads going to a known and rational destination Any roads seemingly going nowhere or ending abruptly</td>
<td></td>
<td></td>
</tr>
<tr>
<td>x6</td>
<td>Buildings</td>
<td>Location, construction, activity, heat emission Are they radiating an unnecessary amount of heat</td>
<td></td>
<td></td>
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<tr>
<td>x7</td>
<td>People</td>
<td>Number, households, appearance, biometric data, identification Is their number coherent to the known activity of the building Is there any group of people entering a building and not leaving within a logical time Do they wear dusty clothes, muddy shoes in a dry climate</td>
<td></td>
<td></td>
</tr>
<tr>
<td>x8</td>
<td>Vehicles</td>
<td>Parked, active around a building, types, licence plates, appearance Is their types or number compatible with the known activity of the building Why are so many cars parked outside this small isolated building What is their aspect Are their covered with dust Do they have licence plates matching the area</td>
<td></td>
<td></td>
</tr>
<tr>
<td>x9</td>
<td>Garbage</td>
<td>Collection, frequency, volume, aspect In-time with the buildings or areas they are serving</td>
<td></td>
<td></td>
</tr>
<tr>
<td>x10</td>
<td>Telephone</td>
<td>Lines, number, signals, content Too many multiple signals coming from the same or from a remote location, or not enough signals</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Patterns and Anomalies

Let’s use electricity consumption as a particularly simplified example of pattern. Having “learnt” and adjusted the synaptic weights, and when keying the appropriate TO, the ANN will determine the amount of electricity that in theory should be consumed by a specific targeted site.

This theoretical consumption is based on the following TO (non-exhaustive list):

- Building physical characteristics (including construction materials, type of isolation, etc.)

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16 Bowes, Joshua; Newdigate, Mark et al., “The enemy below: Preparing ground forces for subterranean warfare” US Naval Postgraduate School, December 2013
- Climate average temperature
- External temperature at the time of observation
- Occupants (number of households, sizes of families, etc.)
- Appliances (estimated from the socio-economic level of the households, local purchasing habits, number of TV dishes, etc.)

When comparing the calculated consumption to the actual figure, any repetitive deviations will be considered as an anomaly, as it is known that electricity is needed to power digging equipment, ventilation and extra lights. However, one may rightly say that all this equipment may not be going through the normal electric circuit within the targeted site and use their own cables instead. Then TO from imagery – connected to other nodes of the ANN – would have determined whether electric cables (numbers, sizes and voltage) are coherent with the buildings they are connected to17.

The ANN will also receive inputs from the geophysics tools (e.g. seismic, acoustic or GPRs data). So a weak seismic signal (which may not have been noticed in isolation) may carry a different significance when associated with inputs from TO, once processed through the ANN.

Conclusion

Traditional geophysics tools are improving and helping the discovery of the locations of subterranean complexes. However, a pattern recognition system like an ANN – which would ingest and process thousands of data, including data from geophysics – would be able to produce outputs indicating the occurrence of a specific subterranean activity. Using ANN for pattern recognition and anomaly detection is nothing new and fits in the trend that major research organisations are setting.

We believe that our suggested approach would improve the detection of subterranean complexes. Although some may think that we are getting into an ultra-complex process, we should remind them that currently some far-fetched artificial intelligence tools (AI) are tested to predict human behaviour. As an example, DARPA is said to be testing an AI system, which can watch and predict what a person will “likely” do in the future, using real-time video surveillance feeds. This program, called PetaVision, is a “multi-modal approach to real-time video analysis; biologically-inspired, hierarchical neural networks to detect objects of interest in streaming video by combining texture/colour, shape and motion/depth cues.”

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17 Electric cables are also an important TO and leads to queries such as, are they connected to a building or going nowhere, are they any isolated power transformer, could any cable be kinked to its power source and its destination.