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LANDMINE DETECTION WITH DRONES

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ABSTRACT

The opposing forces often laid antitank or antipersonnel minefields during wars and other armed conflicts. However, countries those ratified the Ottawa Treaty had abandoned using antipersonnel landmines in the future, the mines laid earlier are still can be found in huge numbers buried under the soil and they cause serious injuries to several people. Safe detection of mines, other dangerous explosive devices and the precise determination of their location sometimes require specific equipment. The authors introduce certain aerial vehicles and some of their special detection devices those can be used for locating landmines from the air.

KEYWORDS: antipersonnel mine, drone, mine detection, minefield, unmanned aerial vehicle

1. Introduction

In former theatres of war, the landmines and other explosive remnants of war (ERW) hidden under the surface cause a serious problem for long decades. A non-governmental organization (NGO), the International Campaign to Ban Landmines publishes its annual report about the global landmine condition of the world in every November since 1999. According this summary 5554 people of 50 countries died or suffered injury in 2019 due to landmine or ERW explosions: 2170 dead, 3357 wounded, 27 further state unknown (ICBL–CMC: Landmine Monitor, 2020). Almost 80 % of them were civilian (4466 people), but persons executing mine detection tasks (23) and other military personnel (944) also were victims of the blasts (121 affiliation unknown). It is shocking that 35% of victims (1562 persons) were children (580 dead, 979 wounded, 3 unknown).

For that very reason, it is important to detect the hidden explosive devices very soon and make safe the former areas of war. International organizations and different NGOs make a huge effort to reach this status quickly but mine detection and removal happens very slowly, though the amount of mines found yearly is considerable.

2. Landmines and Other Explosive Devices

The landmines are prefabricated explosive devices; they include antitank, antipersonnel, anti-helicopter and anti-assault mines. During landmine detection and area clearance the first two categories are the most common, therefore we confine to introduce only those.

The antitank mines attack tanks and combat vehicles by destroying their track/wheels, the engine and armament or penetrate the armour and kill the crew.

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Blast effect antitank mines contain up to 12-15 kg high explosive and layed on the ground or buried 5-15 cm below the surface. These mines used the blast effect to cut tracks or disrupt road wheels after they got a pressure of about 150-300 kg. Many types of antitank mines use a shaped charge to produce this result. When a shaped charge explodes, it projects a stream of molten metal and gas, which can even penetrate considerable thickness of armor plate. They are normally round or square; the case is made of metal or plastic and range in size from 20 to 40 centimeters in diameter and 10-15 cm in height. Some antitank mines can attack the full width of a tank or a vehicle. Older versions are detonated by tilt rods, the novel ones by magnetic fuses; the mine's charge detonates exactly underneath the belly of the vehicle. The side-attack antitank mine is actually a big amount of explosive charge packed behind a heavy steel plate and attached to a tripod against the side of armored vehicles and tanks. When the mine detonates, the steel plate formed into a slug and propelled toward the target by the explosive. They either use a breakwire or can be command-detonated. The novel developments of area defense mines are autonomous, intelligent mine systems, that destroy targets without human guidance. They observe the target at a distance of 500-600 m and destroy it 70-100 m away from mine. Their high explosive warhead mostly attached to an acoustic/ seismic and infrared sensor package.

The antipersonnel landmine is an explosive device designed to injure or kill anyone. The pressure operated blast mines are designed to activate when the victim steps directly on the mine. Some are quite small, have a plastic case, while others are larger and may have a wooden, glass or metal case, and in some cases are improvised in the field. Generally, they are cylindrical in shape, ranging in size from 5 to 15 cm in diameter and 5 to 10 cm in height. They might be laid directly on the ground surface or buried with 4-10 cm of covering. When it is detonated, the blast of its 100-300 g explosive charge drives fragments of the mine case, along with dirt, gravel up the victim's leg. These landmines are very dangerous; due to their dimensions and hidden laying it is the most difficult to detect and see. The fragmentation mines usually laid above ground. Most fragmentation mines are supported on stakes – hence the name "stake mine" – or attached with mounting brackets to man-made structures, trees, etc. Most of these mines have metal casings designed to rupture into fragments upon the detonation of the mine charge. They usually activated by tripwire; when the victim walks into or brushes against the tripwire with enough force to generate a pull of about 1 kg, the mine detonates, causing fragmentation projected over the target area up to 20-25 meters. The bounding mines may combine blast and fragmentation effects, although most rely on fragments for their effectiveness. This mine usually designed to be buried and concealed, often with only a small fuse mechanism with a single spike or multiple spikes protruding above ground. When a victim applies pressure to the tripwire or steps on the fuse, a small explosive charge projects the mine body upwards from a barrel assembly to a point above ground level where an anchor cable secured to the assembly pulls a pin from a fuse on the main body. When the mine reaches a height of approximately 0.5-1.5 meter, the main charge detonates, scattering fragments in a 360-degree horizontal arc, which can kill up to a distance of about 35 meters and cause severe injury up to 100 meters. They are generally 15 cm in diameter and 25-30 cm in height, the tripwires can run as far as 30 meters from the spikes. Directional fragmentation mines are also mounted above the ground and contain pre-formed metal fragments located in front of an explosive charge. When activated, the mine scatters the fragments over a pre-determinated arc of about 50 meters. They triggered by tripwires or by remote control. Smaller versions shaped like a curved rectangular box, which sits on two legs; the larger, circular shaped versions contain more explosives and bigger metal fragments and can easily destroy soft-skinned vehicles, too (Tóth, Lukács & Volszky, 2012).

With regard to the hazard caused by antipersonnel landmines, as a result of international cooperation, a "Mine Ban Treaty" was signed by 121 countries in Ottawa, 3 December 1997. The Treaty had entered into force on 1 March 1999, and since then further countries joined, now it has 164 member states and 1 subscriber. However, 32 countries still refused to sign it.

3. Mine Detection Methods

Mine detection during combat operations for military purposes focuses on minefield breaching and clearing a small sector for the troops with 80-90% required efficiency. On the other hand, detection during a humanitarian mission means that the entire area has to be cleared from all kind of mines and explosive devices; the accuracy and efficiency of the survey must almost reach 100 %.

Unfortunately, mines often were laid without any recording during wars and conflicts; and nowadays it makes almost impossible to identify the location of earlier minefields and determining the amount and type of mines in a minefield. Several types of landmines made of plastic body and without any metal parts, which makes it even more difficult to detect them. Small mines and improvised explosive devices (IED) left behind after the conflict without any marking signs endanger civilian inhabitants, economy system, infrastructure and persons try to survey them (Horváth & Szatai, 2020).

Landmines laid on the surface are easy to observe and detect, depends on the colour of the mine body. Method of detecting landmines, which buried under the surface and invisible for human eyes mostly depends on the dimension of the area, characteristic of the terrain, required efficiency and the available devices for reconnaissance. Major mine detection methods and detectors based on mechanical, biological/chemical, electromagnetic, acoustic mechanism or on their combinated concept (Lukács, 2006; Kovács, 2008).

Basic equipment of the mechanical mine detection is the mine probe. The manual determination whether an item under the surface is a mine or just a harmless object is very dangerous. This survey method is the most effective, but the slowest. The earlier probes were made of steel, but due to magnetic mine fuses, the novel versions have a special metal alloy or strong plastic prodder. The newest model as a smart detector (Figure no. 1) gives a signal to the operator when detects something, and even can determine the material type of a mine body. This probe is under testing now in humanitarian demining tasks.

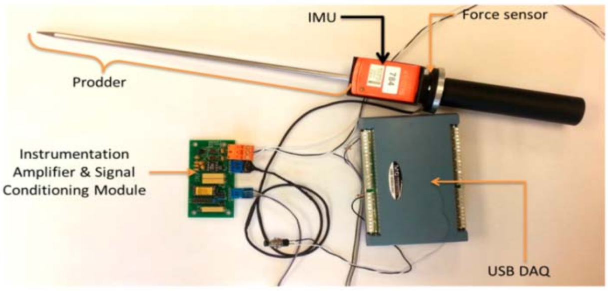

Figure no. 1: *Main parts of a "smart" mine probe*
(Source: https://www.mdpi.com/sensors/sensors-16-00965/article_deploy/html/images/sensors-16-00965-g003-1024.png)

The biological/chemical detection technology is based on explosive vapor identification. The explosive charge of the buried landmine always release molecular parts to the surrounding soil. The biological detection method includes the use of animals (dogs, rats, bees, insects) and different microorganisms to “smell” the presence of explosives. Presence the most of animals assist humanitarian demining is not feasible in military combat operations. Their effectiveness depends on their training, vapor concentrations, weather and many environmental conditions. The bacterial mine detection involves spraying the microorganisms on the mined area and after a few hours, they fluoresce in the presence of TNT. This method strongly depends on soil humidity and temperature. The gas/steam spectrometers also “smell” explosive vapor (usually nitrogen dioxide) like animal noses and have extremely low detection threshold, even 10^{-15} gramm/milliliter. However, the size, weight and power requirement most of these spectrometers limit their use on heavy terrain.

Electromagnetic detectors are the most common equipment and the metal detectors the well-known most of all. They use the electromagnetic induction, sensing changes in the magnetic field and give a signal (sound and/or light) to the operator when detect an adequate amount of metal in 0.1 – 0.5 meter deep under the surface. Modern detectors with pulse induction are capable to find metals in the depth of more than a meter, but landmines without metal parts cannot be detected with these detectors. Detection requires a long time and in a former combat area detector gives lots of false signal due to remained ammo and other metal debris.

The Ground-Penetrating Radar (GPR) emits high frequency radio waves (10-3000 MHz) into the soil then analyzes the returned signal that generated by objects buried under the surface. GPR senses dielectric changes and can find mines with a wide variety of types of casing not just those with metal. The sensing capability depends on the wavelength of the input signal. The effectiveness improves as the wavelength decreases and the frequency increases. The soil moisture and rough ground surfaces also may cause difficulties in detection.

Thermal detection methods use variations in temperatures of areas near landmines relative to surrounding areas. The mines or the soil above them tend to be warmer than surrounding areas during the day but lose heat more quickly at night (Figure no. 2). During the day the soil over the mine accumulates thermal energy and the mine trasports that heat deeper into ground, therefore the soil over a mine becomes warmer than the area around. This method effective only to detect landmines with a thin layer of soil above it and really may used at proper weather conditions. Detectors work on a relatively higher frequency (> 300 GHz) but with low wavelength (< 1 mm), and they can not make difference between types of buried objects.

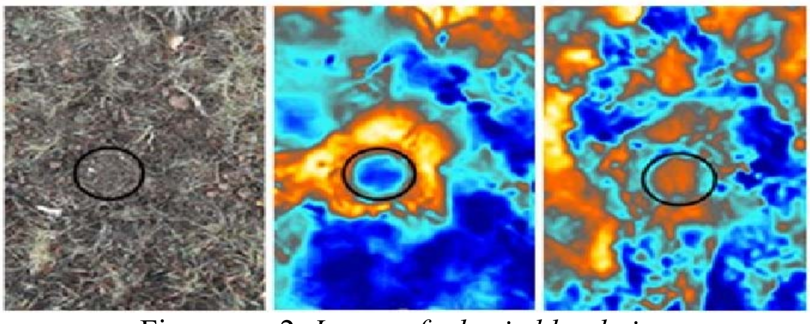

Figure no. 2: *Image of a buried landmine*
a – visual; b – thermal morning; c – thermal afternoon
(Source: Krause, Salahat & Franklin, 2018)

The Nuclear Quadropole Resonance (NQR) is also a radio frequency technology that induces a pulse on a certain frequency. This pulse causes the explosive molecules (nitrogen) to resonate, which induces an electric potential in the receiver coil of the detector. Main weakness of the technology that it cannot locate explosives are incased in metal, because radiowaves not penetrate the mine case. It is also very sensitive to the distance between explosive and detection coil; therefore it must be operated very close to the ground surface.

The acoustic detectors vibrate the buried landmines with sound or seismic waves. The different materials in the soil vibrate differently when exposed these low frequency (50-1000 Hz) waves. The detector generates the sound waves from a high-output loudspeaker or a seismic wave generator. The special sensors – vibrometer, microphone, radar or ultrasonic device – in the detector can detect the waves reflected from a hidden object. Greatest limitation of this method is the hard, frozen soil that may limit the sensor's capability.

The detection equipment and devices we flashed above can be operated as handheld detectors or they need a carrying vehicle, depending on their weight and dimensions. Trucks, vans are the best carrying vehicles for those. Some technologies are under further development and were not tested in live situation at all. Detecting robots also increasingly come into wide use, they can be operated by vireless remote control with a safe distance from mines. The vehicles those are able to fly and sense mines from the air play significant role in minefield detection, too.

4. Mine Detection with Unmanned Aerial Vehicles

Conventional airplanes and helicopter as well as unmanned aerial vehicles (UAV) are all suitable for mine detection from the air; they all might be an appropriate platform for the majority of detection devices we outlined above.

Main advantages of detection from air are the safety and time. Aerial vehicles do not contact with ground during the survey, they move in different heights following the terrain, therefore direct contact with mines and fuses is not possible. Aerial vehicles move faster than ground ones while working, they can check greater area during a given period and can move above the most difficult terrain. With an integrated global positioning system (GPS) drone immediately forwards the correct coordinates of each discovered landmines to a digital map via a wireless communication system.

The majority of UAVs can rise vertically and does not need long runways for take-off and landing. Airplanes and helicopters are not the best aeriel vehicles for detection of closely minefields and sometimes their usage is not necessary at all. They are very expensive, piloting requires a long special training, and sometimes they indispensable for high importance military operations other than mine detection. On the other hand, drones are very suitable for minefield detection, limited by weather conditions like velocity of wind, thunderstorm, snowfall, icing and the range of action. Main differences between drones and airplanes/helicopters that drones controlled by an operator from the ground or its task was programmed earlier and works automatically. The other difference is the dimensions: drones are far smaller and lighter. They are ablo to fly very low, hover and turn around, move in confined places, cheap and simple to operate. They might be a suitable platform for majority of mine detection equipment.

On the following pages, we only flash the employment and features of multi rotary-wing drones as the most frequented aerial vehicles for mine detection. At the beginning, drones had four rotary-wings, later six or eight (quadro-, hexa-, octocopter), because the more rotors make drone more stable in sudden windblows. If one of the rotors got damaged, the others easily compensate its power. When a drone works as an independent automatic vehicle, it needs a few complementary device like altimeter, gyroscope, speedometer, GPS and a good communication system. It is not necessary to equip drones with armament for mine detecting tasks; weight of detector is enough useful load. The reconnaissance usually made in a close distance and low height, therefore short range (maximum 1-2 km) and low flight (maximum 50 m) drones are perfect for this task (Ember & Kovács, 2020). Now, let us see a few examples.

We can observe a metal detector as the most common equipment for mine searching combined with an infrared (IR) camera installed on a 6-rotor drone (Figure no. 3). During the search drone follows the terrain, continuously moves 10 centimeters from surface.

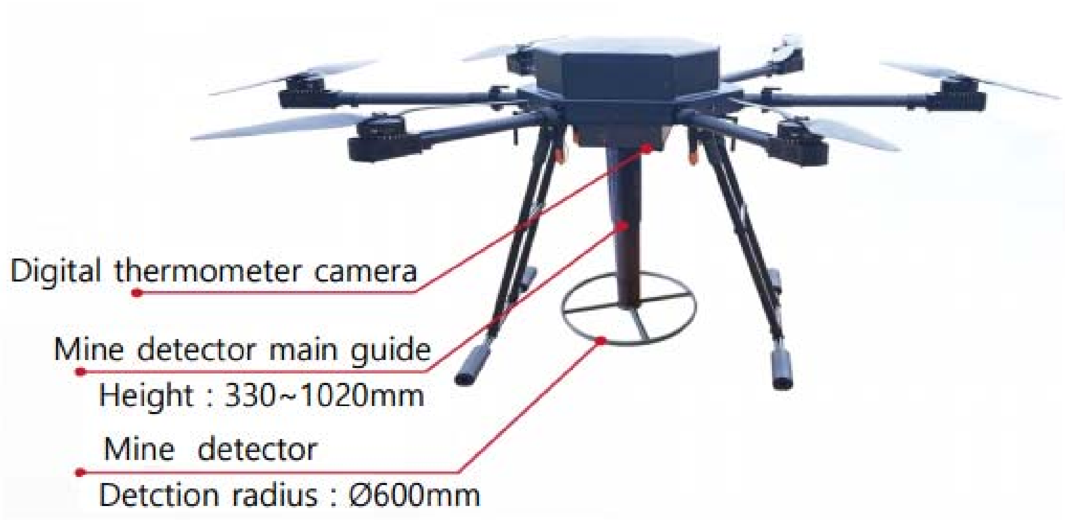

Figure no. 3: *Hexacopter with a metal detector and IR camera*
(Source: http://www.cw-tpm.com/bmcnet_uploads/2019/09/Surveillance-Reconnaissance-and-Landmine-Detection-Drones-System-en.jpg)

Distance of the induction metal detector from the surface variable between 3.3 and 10.2 centimeters with a telescopic leg. Weight of detectors (metal and IR) is altogether 2.8 kg but the bearing capacity is 10 kg. The 20000-mAh battery ensures 30 minutes working time. Drone can fly up to 15 meters with 50 km/h maximum speed. During the search it moves with 3.5 km/h and might controlled manually or able to work automatically.

Although the following drone has only four arms but every arm has two rotors operated by independent electrical motors (Figure no. 4). Due to this motor configuration, if one or two motors fail in emergency situations, the drone is still capable of flying safely. This drone was designed with high performance carbon fibre to reduce its weight (5.5 kg) and increase flight time up to 60 minutes by the modern lithium polymer battery. The load-bearing capacity is 6 kg, far enough for the high definition (HD) camera. Dimensions are 63 x 54 x 23 centimeters, the maximum flying speed is 75 km/h. Propellers are 38.5 centimeters long and can move the drone in a 88 km/h windblow.

Figure no. 4: *Quadrokopter with double rotors and an optical camera*
(Source: https://minekafon.org/wp-content/uploads/2019/09/DestinyBLACK-Perspectiveview-1024x640.jpg)

The next drone (Figure no. 5) is an octocopter with eight arms and one rotor on each. It can be equipped with groung penetrating radars operate on three different frequencies (90, 120 and 260 MHz) that scan the ground in different depth. The weight of drone is between 14.1-14.8 kg depends on the GPR type, the flying time between 15-20 minutes, flying speed 2 m/sec.

Figure no. 5: *Octocopter with a GPR*
(Source: https://www.epequip.com/wp-content/uploads/2016/10/AllHazards_DetectionDiagnostics_Metal_Amulet_03.jpg)

The drone immediately forwards the survey data to a data processor that shows the layer of soil on a monitor outlined with the exact loaction and depth of every irregular structured objects under the surface.

5. Conclusion

The drones, just like the mine detecting devices are under progressive development. Due to miniaturization, the mini, micro and nano drones spread wordwide very soon, however their limited load-bearing capacity might be not enough to deliver and operate all detectors we had outlined. The other field of development is to increase the available amount of energy that extends the range of operation and lengthens the flying-time (working time) of the drone. Utilization of solar energy with solar cells may be a good solution but the part of the day and the cloudy weather limit available energy. The other solution is using novel, modern batteries like lithium polymer, which have longer lifetime than conventional lithium or nickel-cadmium batteries.

Further development of the drone technlogy probably will be the widening of application. In the future drones will help not only in searching of landmines but in destructing them, too. They deliver an explosive charge above the discovered landmine, the operator see the camera picture for correct placement, after the drone leaves danger zone the charge remotely detonated and landmine destroyed. In special circumstances, a drone might even safely destroy a whole minefield with this method.

As the flashed examples above show, drones are suitable for mine detection with most of the different detectors. The special detecting devices, which are under current development and have bigger dimensions, weight and energy demand may exceed the actual drone capabilities. Therefore, improvement of load-bearing capacity is one of the significant fields of drone development.

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