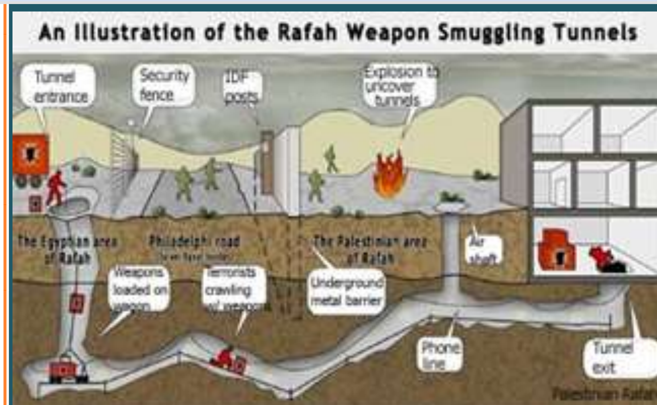
2015

Tunnel Warfare Robot Technologies



Homeland Security Research Corp.

Tunnel Warfare Robot Technologies

August 2015

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1.1 Subterranean Warfare

- Future Subterranean Warfare technologies and tactics will be based on 3 elements:
  1. Clandestine tunnels & underground structures detection systems will be based on fused Multi-Modal Multi-Sensors hardware, algorithms and architecture.
  2. Proactive "Detect and Kill" Subterranean Warfare, in which remotely controlled subterranean guided robots will search, detect and combat the opponent tunnels and buried structures. This will open a new era of "Subterranean Warfare" in which a host of spiral ever-changing technologies and tactics will be employed by terrorists, criminals, security and armed forces.
  3. Future Asymmetric wars will include future warfighters Subterranean Warfare means and tactics.

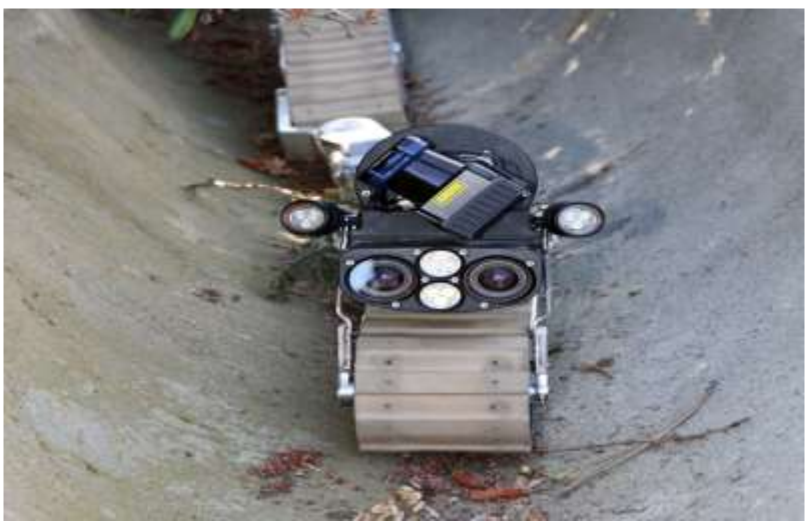
1.2 Subterranean Warfare Robots Technologies

- Asymmetric underground maneuverability and operability is shaping the modern battlespace in urban and complex terrain, offering a clear benefit to the irregular side. The fierce fighting between Israel and the Palestinian terror organizations in Gaza is highlighting the growing need for technologies that can assist the regular military operating in the subterranean dimension.
- Tunnels warfare is not new, in fact it has been part of military history since ancient times, through the 20th century, but has been abandoned by modern military with the introduction of mobile warfare, which rendered the static and slow subterranean warfare useless in face of rapid, dynamic enemy. During the 21st century Subterranean Warfare emerged once again, as insurgents turned to the underground domain pressed by overwhelming technologically-driven Intelligence, Surveillance and airborne reconnaissance (ISR) capabilities mastered by regular military forces, particularly western militaries.
- In an effort to extend the military capabilities to operate in the subterranean environment (Sbt OE) the US Army Rapid Equipping Force (REF) has published a call for information for industry, to provide a range of solutions for this challenge. Among the tools the Army is looking for are

measures improving underground mobility, using both manned and robotic equipment. Operating robots within the confined space of the tunnel is quite a challenge, as remotely controlled robots must deliver effective orientation beyond line of sight. Wireless communication with the robot is another issue requiring deployment of repeaters to extend its range. Orientation without GPS is also a challenge, which can be solved by mapping the subterranean space, although this process may require time.

- The payload developed for the Counter Tunnel Robot System utilizes a spinning 2D lidar sensor that provides 3D coverage, stereo cameras, and inertial sensors. Visual odometry and inertial sensors and registered liar point clouds are also used to enable the robot to autonomously find its way back to the original ingress point
- Autonomous operation of unmanned vehicles, either unmanned ground (UGV), air vehicles (UAV) or ground crawlers (insects or snake like robots) can overcome this challenge, when such robots are given the necessary sensory inputs (sonars, laser scanners etc.) to maintain situational awareness and directional control. However, adding those features to existing robots could be quiet challenging, when packed in a small footprint. Also required are new technologies improving underground communications, navigation and situational awareness.

Figure 1 - Counter Tunnel Robot System Utilizing a Spinning 2D Lidar Sensor that Provides 3D Coverage, Cameras, Inertial Sensors and an Explosive Payload.



(**Source**: US Navy)

Breeching systems are also required, particularly ‘cold’ breeching devices that would enable soldiers to overcome barriers without using explosives in the confined space of the _ tunnel. Compact ladders and rappelling equipment may also be required to overcome vertical obstacles.

After the attacks from Gaza in 2006 and 2014, when Palestinians infiltrated into Israel through a ‘strike tunnel’, killed two soldiers and abducted Gilad Shalit, the IDF elevated the threat of strike tunnels including this challenge among its highest priorities.

Particularly the detection of tunnels as an urgent operational need. Many technologies were evaluated, and some actually put to the test, at a special test range that has been established by the Israel MOD. Among the systems considered were seismic sensors, designed to detect subterranean work in progress, trenching systems that could open deep trenches in the ground, in an effort to uncover tunnels penetrating into Israel, even flood suspected areas to disable tunnels was considered.

A parallel effort was also conducted by the USA, as part of a joint program sponsored by the US Army and department of Homeland Security (DHS). As a single technological solution has proved marginal at best, a combination of a number of sensors could provide better results in the detection of underground activity. In 2007 Georgia Tech has studied the use of combined electromagnetic and seismic sensors to detect shallow tunnels. In 2009 the US Department of Homeland Defense has tested an unmanned aerial vehicle carrying hyper spectral payload working on a Back in the USA, similar technological efforts are directed at remote sensing.

However, so far none has delivered conclusive results. Other capabilities considered for the task include hyper spectral surveillance, precision mapping and surveillance, acoustic/seismic surveillance and measuring minute changes in ground surface – all as part of a relentless effort to uncover the subterranean activities deep under the surface.

Following the repeated Palestinian attacks during Operation Protective Edge (July 2014) the I-MOD announced that yet another technology has been tested and demonstrated promising results.

1.2.1 Tunnel Scouting Robots

1.2.1.1 Tunnel Scouting Robots Technologies

Contemporary reconnaissance underground robots are operated in “remote control” mode, requiring good operator skills to move the robot, understand their surrounding and manipulate their payloads. Some robots are already supporting semi-autonomous operation, enabling the unmanned vehicle to follow relatively complex sets of commands with a single instruction.

Robotic technology is another resource that is of value in working in subterranean environments. Robots are particularly suitable for performing reconnaissance, breaching, and/or recovery operations. They are extremely mobile, can negotiate stairs or obstacles, can be outfitted with day/night cameras, various grippers, and even saws mounted on double-jointed arms.

During a tactical call-out, robots can be mounted with a speaker to relay commands and can also be mounted with a weapon system.

The subterranean environment can be extremely hazardous, with the presence of both natural and man-made obstacles. When available, robots should be utilized for exploration of tunnels before personnel enter.

Once deployed, robots can safely detect such hazards as enemy personnel, booby traps, animals (snakes/insects), and if equipped with a gas meter, oxygen and hazardous gas levels. Robots have different capabilities depending on the robot's category, power source, weight, size, and mobility configuration. Radio frequency (RF) robots operate on line-of-sight, so as the robot advances in a tunnel or takes a turn, the signal may degrade or be lost. The particular mission set and tunnel configuration will dictate the best robot to utilize, should choices be available.

Semi-autonomous capabilities such as climbing stairs, gripping an object or rolling over often requires extensive control that will require a combatant to focus on the robot operation, rather on his own survival, therefore, rendering the robot irrelevant under combat in complex terrain. Semi-autonomous operation is therefore mandatory to make the robot combat efficient. The application of semi-autonomous operation is often utilize advanced yet simple to operate man-machine interfaces and advanced robot operating systems.

Challenging communications and control are also common in operations in built-up and subterranean environment, denying GPS based position location and communications. The integration Differential GPS, (DGPS), interferometric radio-frequency (DF), acoustic (sonar) processing, inertial measurement and azimuth and distance measurement could compensate for better positioning in GPS denied environment. Some of these sensors could also enable some degree of semi-autonomous operation, and allow for several robots to operate simultaneously under a single controller, enabling faster area coverage, especially in indoors and in subterranean reconnaissance operations.

Some of the measures currently used can also provide solutions for subterranean operational challenges. For examples, tunnel scouting robots that are often lowered into the tunnels through ventilation shafts are using a tether – this tether can also deliver the power and communications link to and from the platform, enabling the robot to deploy on its mission unlimited by on-board power or communications range, delivering imagery and data in real time to the operators above ground.

As robots are assuming part of the roles performed by human operators, particularly in dangerous missions, it is obvious they will be used in subterranean environments. However, denied the basic attributes necessary for its operation - navigation, guidance and communications - most military robot are still awaiting some technological solutions when tasked with missions underground.

Figure 2 - A Tunnel Scouting Robots

Operating robots within the confined space of the tunnel is quite a challenge, as remotely controlled robots must deliver effective orientation beyond line of sight. Wireless communication with the robot is another issue requiring deployment of repeaters to extend its range. Orientation without GPS is also a challenge, which can be solved by mapping the subterranean space, although this process may require time.

The robot uses on-board illumination to illuminate the scene. It can also use a thermal camera for more covert surveillance. The robot employs encrypted Mobile Ad Hoc Network (MANET) radio for communications. To enable extended link the robot can deploy radio 'breadcrumbs' along its path, to establish ad-hoc network continuity, enabling the robot to transfer real-time video, voice, and data.

Micro Tactical Ground Robot is lowered by rope into a cave. At a weight of 8.6 kg this ultra-mobile robot can carry 9 kg (20 pounds) of payloads, which include a grip, infrared camera or other systems.

Ground robots can assist human activities underground; sometime even replace manned operations in certain applications. Missions assumed by robot are often safer and, in some applications, faster and more accurate, than those done by humans. As the human, robots also have limitations – particularly in autonomy, situational understanding to their dependence in operator input, which requires reliable communications, either directly or through entities, constantly connecting the subterranean operator to the surface.

1.2.1.2 Robot Perspective of Subterranean Environment

Contemporary ground robots are operated in 'remote control' mode, requiring good operator skills to move the robot, understand their surrounding and manipulate their payloads. Some robots are already supporting semi-autonomous operation, enabling the unmanned vehicle to follow relatively complex sets of commands with a single instruction.

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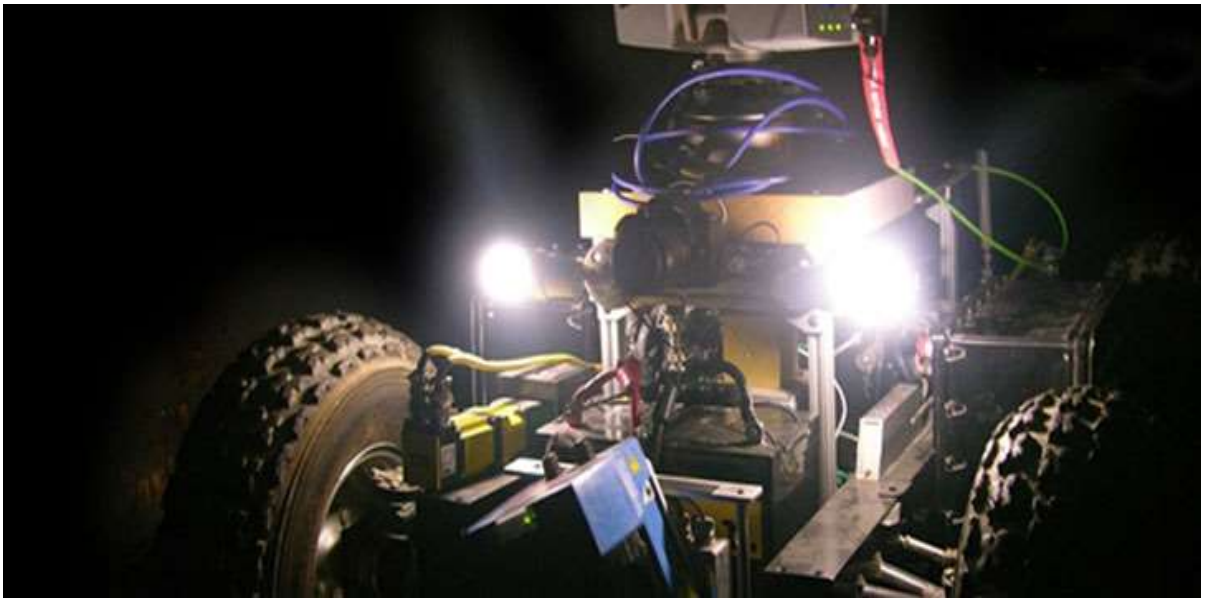
Figure 3 - The Cave Crawler

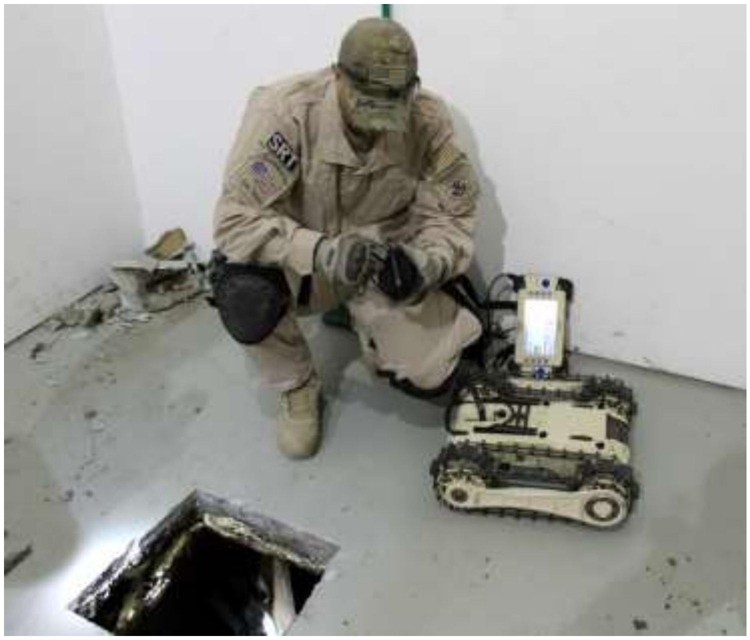


In the early 2000s research projects such as the Groundhog and Cave Crawler developed at the Carnegie Mellon University paved the way for robotic cave exploration and underground archeological research. These projects later evolved into the Gemini Scout – a search and rescue robot developed at Sandia laboratories. Gemini Scout to assist in rescue operations in mines and tunnels. However, this large robot lacked the size and agility to be suitable for tactical missions.

In recent years the Pentagon, and more recently, the inter-agency Combating Terrorism Technical Support Organization (CTTSO) operating under the US Department of Defense. DOD funding directed at subterranean operations, mapping, situational awareness, navigation, obstacle avoidance etc. The Israel Defense Forces (IDF) and British Army have also acquired substantial numbers of MTGRs, for use as miniature, soldier portable UGV. Some of these robots have already entered operational use and are taking part in combat operations.

San Diego Tunnel Task Force is using the MTGR robot to scout smuggling tunnels connecting the Mexican city of Tijuana with San Diego. The MTGRs were provided through the inter-agency Combating Terrorism Technical Support Organization has provided 35 such robots to national and local law enforcement agencies for evaluations and operational use

Figure 4 - Robot Scout a Smuggling Tunnels



1.2.1.3 Micro Tactical Ground Robot

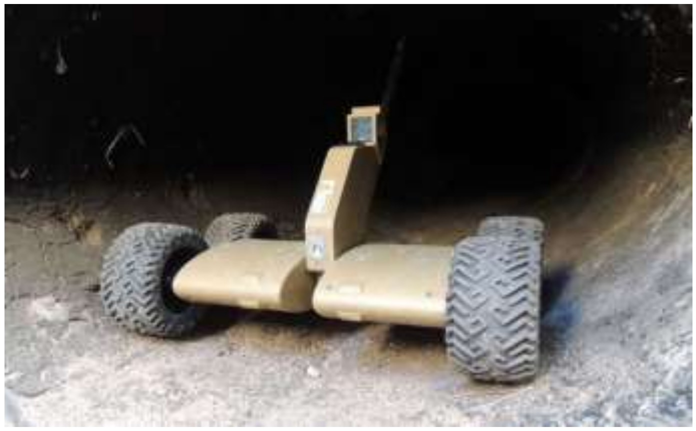
One of the robots found to be suitable for subterranean operation is the Micro Tactical Ground Robot (MTGR) developed by Roboteam. In 2013 CTTSO has allocated $15.6 million to evaluate and field these robots through 2015. Some 100 MTGR robots are already operational with combat teams of the Army Special Operations Command, Naval Special Warfare Command, as well interagency tactical units such as the FBI-Hostage Rescue Team, Border Patrol Special Operations Group, where they recently took part in detection of tunnels along the US-Mexican border in Tijuana. CTTSO plans to provide 35 MTGRs to interagency tactical units or domestic operations. The Israeli and British Army have followed CTTSO recently, fielding the MTGR man-portable micro-robot. Among the missions recently assigned to the MTGR are underground tunnel reconnaissance, a mission bringing the MTGR’s small dimensions and unique networking capabilities to bear.

In addition to special forces and other infantry units in the US, Israeli and British military, the California Customs and Border Patrol (CBP) tunnel task force has been using the MTGR on the US-Mexican border have expanded their surveillance capabilities with the introduction of MTGR robots provided by CTTSO. The robots already demonstrated their worth detecting smuggling tunnels linking Tijuana and San Diego.

A Tunnel Task Force operating in San Diego, CA San Diego Tunnel Task Force, is supported by Homeland Security Investigations (HSI); Customs and Border

Protection (CBP) – Border Patrol; the Drug Enforcement Administration (DEA) and the U.S. Attorney's Office.

Figure 5 - A Micro Tactical Ground Robot



Another robot adapted for tunnel surveillance is the Pointman Small UGV (SUGV). According to ARA over 50 Pointman Tactical Robots are already deployed with police, SWAT, government and first responder teams across the United States. This wheeled robot, built by ARA is currently has recently been used in tunnel detection, operating around Nogales, on the Arizona border.

The Counter Tunnel robot configured to move inside a tunnel, using 'tank mode' moving on two tracks in parallel. When negotiating obstacles the robot can transform to move in snake style motion. The robot is equipped with a stereo camera and 2D Lidar payloads.

Rapid Reaction Tunnel Detection (R2TD) robots

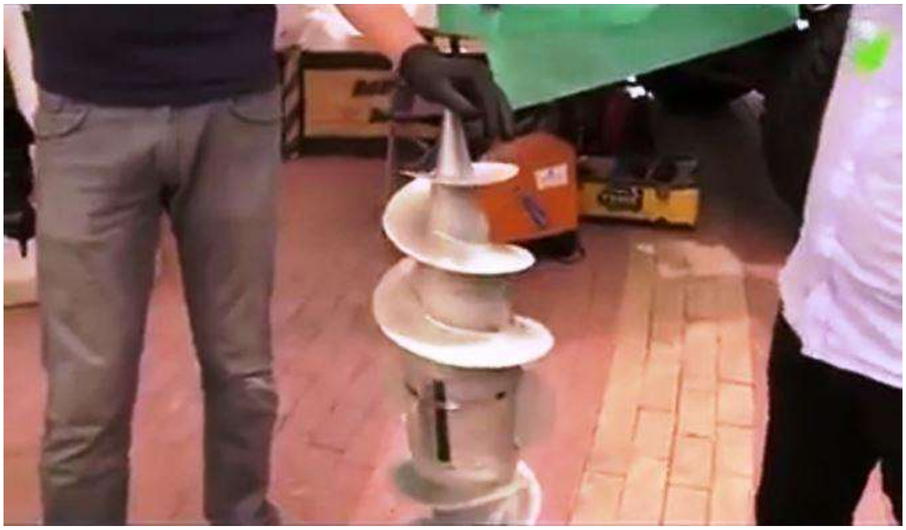
The Counter Tunnel System project pursued and sponsored by the Office of Secretary of Defense (OSD) Joint Ground Robotics Enterprise (JGRE) under the Rapid Reaction Tunnel Detection (R2TD) Joint Capability Technology Demonstration (JCTD) was launched in 2011 and has reached limited field testing in 2013. A prototype robotic system for counter-tunnel operations, the Counter Runnel robot is designed to conduct exploration, mapping, and characterization of tunnels with high level autonomy, providing a safe and effective solution for three-dimensional (3D) localization, mapping, and characterization of a tunnel environment. The Counter Tunnel robot tested under the R2TD JCTD can deploy into tunnels up to 30 meter deep through boreholes as narrow as 20 cm.

1.2.2 "Seek and Kill" Attack-Robots

Two Israeli inventors have presented a prototype of a robot that can dig through earth at a range of several Km; weighs 5-10kg and can locate Clandestine Tunnels & Underground Structures. It can also cover its surface tracks.

The remotely controlled robot can climb from any point, without leaving a trace. The battery life span is currently at 3 hours per recharge. It can determine the length of tunnels and its points of entry.

Figure 6 - The "Seek and Kill" Tunnel Attack Robot Prototype



Source: http://analyses193.rssing.com/chan-26557358/all_p4.html and www.youtube.com/watch ?v=tH5LzUmP9sQ

According to the inventors, they passed a performance test of the robot close to the Gaza-Israel border. The robot can be used as an attack robot by guiding it to detect and demolish tunnels using robot mounted explosives. According to the inventors, the cost of a robot is a few thousand dollars.

1.2.3 JGRE Robot Program

This counter-tunnel effort was funded by the Joint Ground Robotics Enterprise (JGRE) from fiscal year 10-13, run jointly by SPAWAR Systems Center (SSC) Pacific and Air Force Robotics Lab Airbase Technologies Division (AFRL/RXQ) Tyndall, and was a complementary development effort to the Rapid Reaction Tunnel Detection (R2TD) Joint Capability Technology Demonstration (JCTD), which addressed the objective tunnel exploration requirements.

1.2.4 DTRA Robotic Underground Munition (RUM) Project

The Weapons and Capabilities Division (RD-CXW) of the Defense Threat Reduction Agency (DTRA) published by March 2010 a RFI for advanced technologies relevant to the development of a Robotic Underground Munition (RUM). The RUM would be a one-time use, air-delivered, highly mobile vehicle having certain characteristics similar to an unmanned ground vehicle.

Besides relevant advanced technologies, RD-CXW is also asked for interested sources capable of performing as the weapon development prime and able to integrate technologies and produce and demonstrate a prototype robotic munition.

According to the solicitation, the following technology development objectives relate to key RUM technologies that could benefit from the technology development:

1. Survivable underground communication system.
2. Capabilities to efficiently overcome natural and man-made obstacles.
3. Robust sensors and perception.

Other technologies necessary to produce viable RUM are assessed to be at a higher technology readiness level (TRL) or would better profit from further development at a later date or by the weapon developer. As such, a potential prime's knowledge or capabilities in these areas is desired. These include:

1. Payload and fuzing development, integration and demonstration. The payload must be compatible with inflight and ground environments including long term storage under adverse temperature conditions, as well as all DOD insensitive munitions and other safety requirements.
2. Viable passive and active defensive and offensive systems.
3. Autonomous underground controls and navigation.
4. Vehicle control logic to avoid, traverse, neutralize or defeat natural and man-made obstacles.
5. Safe separation and accurate soft landing form an aircraft.

The RFI required that the bidders of the RUM weapon development prime must have expertise and capability in all of the following areas:

1. Robotic vehicle design and manufacture
2. Sensor integration and autonomous controls
3. Munition design and manufacture
4. Aircraft integration
5. Mission planning

More information can be found at:

[Subterranean Warfare (Tunnels & Underground Structures Detection and Subterranean Robots) Technologies: Global Market – 2015-2020]