Cooperative Unmanned Air and Ground Vehicles for Landmine Detection

Moustafa M. Kurdi[1], Alex K. Dadykin[2], Imad A. Elzein[3], and Ali K. Ibrahim[2]

[1] American University of Technology, Beirut, Lebanon
[2] Belarusian National Technical University, Minsk, Belarus
[3] International University in Beirut, Beirut, Lebanon
Email: mostafa.alkirdi@aut.edu; alex_05_07@rambler.ru; imad.zein@liu.edu.lb; alik.ibrahim2015@gmail.com

Abstract—**The unmanned aerial vehicle used in this research is multi-functional quadcopter with infrared camera and Ground Penetrating Radar (GPR). The unmanned aerial vehicle detects the landmines using infrared camera and GPR; maps a pin in digital map for future use by ground vehicle. The ground vehicle used in this research is Belarus132N mobile robot. It has the following onboard sensors: stereo pair camera, GPS, and image processing system. The ground vehicle will use onboard sensors: stereo pair camera, GPS and the map provided by the quadcopter to traverse the region, and locate the mapped landmines. The base station consists of a laptop that provides a communication link between the aerial and ground vehicle systems and for saving information from any destruction. This proposed system will demonstrate how an air-ground vehicle system use to cooperatively detect, locate and traverse of landmines.**

Index Terms—**ground penetrating radar, multi-functional mobile robot, quadcopter mobile robot demining robots, thermography image**

I. INTRODUCTION

One of the unsolved problems with which humanity entered the third millennium is the problem of "humanitarian demining". After the end of the Second World War, numerous military conflicts continued to arise in all regions of the world, generated by national liberation and civil wars, international and inter-national confrontations. Official data of the United Nations show that in all regions of the world, there are about 110 million mines in the territories of 64 countries and about 100 million of them are in warehouses in readiness for immediate use.

According to the International Red Cross, around 800 people die on a monthly basis, most of them civilians; since 1975, over a million people have been killed or injured on mines. There are two types of landmines: anti-tank, and anti-personnel.

A reliable search for anti-personnel mines is the main task in the problem of humanitarian demining. Antipersonnel mines hit the enemy's living force with a shock wave (high-explosive mines) or mines that have

flown out of the hull in advance in the form of pellets, cylinders, arrows, or fragments formed by crushing the shell (fragmentation mines) [1].

Anti-vehicle mine is a sort of land mine intended to harm or crush vehicles including tanks and protected battling vehicles.

Ground penetrating radar (GPR) is an electromagnetic device, which is one of the technologies that has been extensively researched as a means of improving the efficiency of mine operations (detection and removal). In addition to the geological and civil engineering applications, GPR uses for both civilian and military applications of landmine detection.

Thermal imaging is a strategy for enhancing visibility of objects in a dark environment by identifying the items' infrared radiation and making a picture dependent on that data. Thermal image has many advantages, such as:

1) Visual picture as temperatures over a large area.
2) Catch moving objects in real-time manner.
3) Utilized to discover surrenders shafts, channels and other metal or plastic parts.
4) Utilized to distinguish objects and people in dim spots.

Thermography system of object detection is designed for temperatures from a given point in the thermal image and projects its location directly on the digital map, based on dynamic scales coordinates and colors set by the user that help mobile to freely navigate in unknown environment especially in bad weather conditions (smoke, fog coated region).
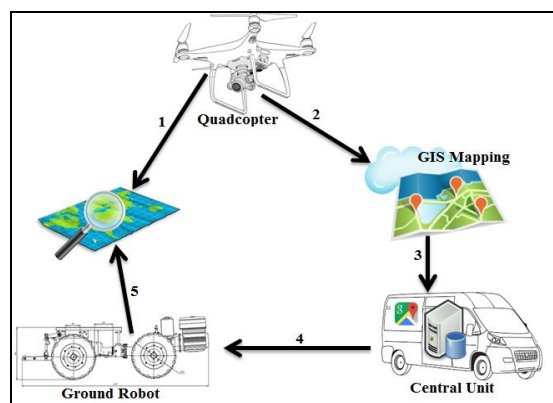

Fig. 1. General architecture of the proposed system.

We design and develop an intelligent system of unmanned air vehicle and unmanned ground vehicle named quadcopter mobile robotic system (QMRS) [2], as shown in Fig. 1, which performs several operations, as a movement in specified direction, detect landmine by quadcopter, project the landmine by geographic information system (GIS) into digital map and navigate the projected landmine on digital map by mobile robot.

II. Landmine Detection

Landmines are unmistakable weapons, and they are unsafe and powerful, inexpensive, simple to produce and bury. Landmine consists of a ring mechanism, detonator that sets off the booster charge, and an explosive charge that constitutes the body of the mine and plastic, wood, ceramic or metal casing that contains the majority of the described elements. A landmine is a kind of independent-contained explosive device, which is set into the ground to constitute a mine area, and it is designed to devastate or harm human and equipment [3].

Mines are produced in different shapes, sizes, explosive intensity and fusing. Both anti-personnel and anti-tank landmines come in different shapes and sizes, and can be covered by metal, plastic, wood, or pottery. They buried underground at various depths, placed on the surface, planted within buildings and on the streets, or covered by plant overgrowth.

Various techniques used for the detection of landmines such as: 1) optical; 2) thermal imaging; 3) nuclear; 4) metal detector; 5) electromagnetic; 6) acoustic; 7) mechanical methods; 8) biological; and 9) latest methods.

Depending on the tactics of use, mines have different weight and size dimensions and installation methods. Mines with the smallest dimensions (from 3 cm to 10 cm in height) are anti-personnel and are installed on the surface from aircraft (for example, helicopters) or manually. The remaining mines are laid in the ground to a depth of 5 cm to 30 cm from the top of the hull, depending on the mechanism of the fuse used [4].

The types considered can be reduced to one form - a cylinder with different ratios of height (h) and diameter (d). In Fig. 2 presents three generalized versions of the ratio diameter/height. The most common type of mine is shown in Fig. 2 a).

Objects with a plastic body are the most difficult to detect due to the small difference in the electrical parameters of the mine material and the environment (Table I).
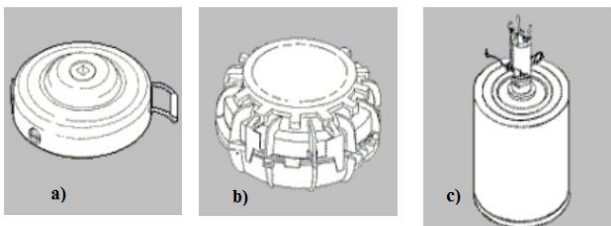

Fig. 2. General form of mines a) cylinder $d = 2.5h$; b) cylinder $d = h$; c) cylinder $d = 0.5h$.

TABLE I. Electrical Parameters of Substances

Substance	Avg. values of permittivity	Material
Plastic	3.3	Housing material
Wood	2.95	
TNT	2.7	Explosive
composition B	2.9	
RDX	3	
Dry sand	4	Environment
Wet sand	25	
Dry limestone	4	
Moist limestone	8	

In addition, when detecting mines, the mine depth is of great importance. The propagation loss of the signal in the soil is high: For example, in loamy soil, the attenuation of the signal at a frequency of 1 GHz can reach 80 dB/m [5].

III. Proposed System

Quadcopter Mobile Robotic System (QMRS) is an efficient system for detection landmines. The system consists of ground robot Belarus-132N, Ground-Penetrating Radar (GPR) and thermal camera attached to multi-functional quadcopter [6].

The procedure for landmine operations by using robot interactions is as follows (Fig. 1):

1. Quadcopter takes off, moves over the region, photograph the area, searches and detects landmine by infrared camera and ground penetrating radar.
2. Quadcopter projects the landmine findings into geographic information system (GIS) mapping.
3. Quadcopter transmits GIS images, collected data to base-station located near to the field of operation.
4. Central unit base station uploads the GIS landmine findings into digital iCloud-google-map, and then it sends the updated digital map to the ground robot.
5. Ground robot uses digital iCloud-google-map to move through the operational area and traverse the landmines.

A. Ground Robot Belarus 132N

Belarus-132N is a ground robot designed and manufactured by an international company from Belarus. It is a 4-wheeled robot with dimensions 120 cm length, 120 cm width, 180 cm height, and 500 kg weight.

It comprises serial frame of tractor Belarus-132N and image processing system; control system; positioning and navigation; microcontroller; communication systems for sending and receiving data; attachments, such as arm as shown in Fig. 3.

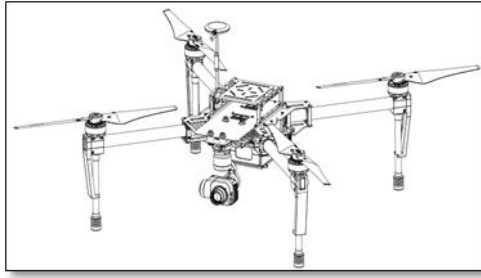Fig. 3. General scheme of mobile Belarus-132N.

Fig. 4. General scheme of multi-functional quadcopter.

Ground robot Belarus-132N has four-types of motion control: i) Driving forward on the route; ii) Turning left or right; iii) Return with rotation; and iv) Driving backward (blind movement).

Our ground-based robot designed to determine their location and their identification, because when using the equipment of the quadcopter of the robotic complex there are a lot of noise and false objects similar to mines. The use of ground-air robot will provide the necessary 100% mine detection.

1) GPS of ground robot

The navigation system identified with GPS gives the following tasks: estimate the position of robot; calculate the optimal navigated route, and deliver to the central base station; receive data/commands from the remote control/central base station; decode commands from the remote sensors and to initiate these programs.

2) Image processing system

The image processing system plays out the following tasks:

1) Accepting flow of data from stereo-pair cameras and hard-disk storage;
2) Compression of video-data with a particular channel and delivery to an external PC operator;
3) Getting a pointer to catch an object/item, catching guideline and instruction, the seizure of the specified and selected object to the issuance of the catch flag to an external PC operator;
4) Calculating of distance to the selected object with the displaying output to external PC operator;
5) Viewing the captured and selected object.

B. Multi-Functional Quadcopter

A quadcopter or unmanned aerial vehicle is a 4-rotor helicopter that uses these four rotors in departing and landing. Quadcopter is a standout amongst the best vertical take-off and landing vehicle with autonomous flight control and stable hovering capabilities (Fig. 4).

The components of quadcopter are frame F450, EMAP Simon 30A, electronic speed controller, EMAX-MT-2213 motor, flight controller board KK v2.0, 2.4 GHz receiver, transmitter, MPU9255–gyroscope–accelerometer–compass, single-board Raspberry Zero W, Wi-Fi adapter, universal GPIO I/O ports, Saitek X52 to ensure full-duplex communication, and 3-cell 2200mAh 25C LiPo Battery.

In Fig. 5, a short pulse generator is connected to a transmitting (TX) antenna. The pulse duration is usually in range of a nanosecond or sub-nanosecond [7]. When a pulse is radiated through the TX antenna, the analog to digital converter (ADC) at the receiver is triggered. The time duration that the pulse needs to travel to the target and back to receiving (RX) antenna has to be sampled with high speed [8].

1) Ground Penetrating Radar (GPR)

Zenmuse XT FLIR Thermal Imaging Camera: Using Zenmuse XT FLIR thermal imaging for small drones brings new capabilities to dozens of applications like search and rescue, the inspection of power lines, cell towers, bridges, substations, and buildings, firefighting, precision agriculture, and natural resource and wildlife protection.

It has multiple lens options (640×512 or 336×256 resolutions) to ensure the right combination of situational awareness, magnification, spot size, and area coverage to suit the mission requirements.

Thermography system consists of several parts: i) the projection on the digital map: link between the system of heat detection and digital maps; ii) Dynamic display by setting the initial coordinates of the image; iii) Control and monitoring.

The visualization of the flight-quadcopter-state and 3-dimensional representation of space is represented by Fig. 6. Quadcopter processes the image form infrared camera to produce a 3D-model for ground robot safe route. To create a 3D-map representation image processing system requires hundreds of overlapping images, as shown in Fig. 7.

2) Coverage path planning

Coverage path planning is the operation of finding efficiently a path that covers all the points of a specific area.
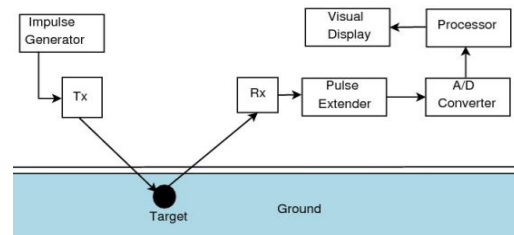

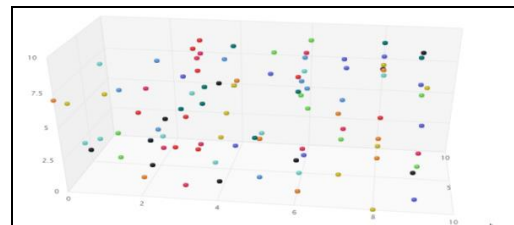Fig. 5. GPR technologies f landmine detection.

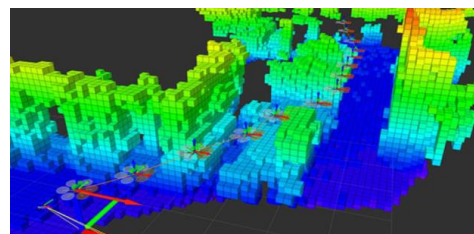Fig. 6. Visualization of the flight state and three-dimensional representation of space.

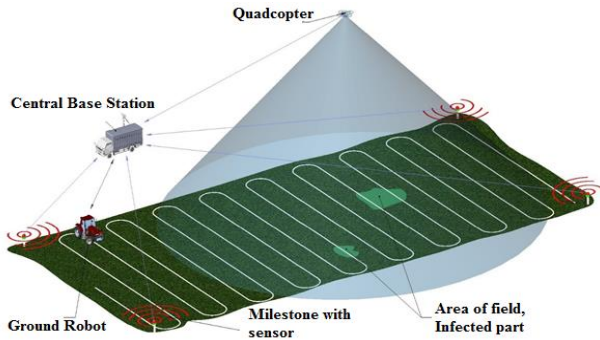Fig. 7. Flight route of the quadcopter based on the infrared camera data.

Fig. 8. General scheme of coverage path planning.

The quadcopter will fly over the area [9] to be covered executing a back and forth motion in rows perpendicular to a given sweep direction, as shown in Fig. 8. The time to cover an area consists of the time to travel along the rows plus the time to turn around at the end of the rows. UAV turns take a significant amount of time: UAV must slow down, stay in hovering, make the turn, and then accelerate.

C. Central Unit Station

The central unit station is responsible of receiving information (detection and data collection) from the quadcopter, and a moving ground robot unit for mine traversing and transferring collecting data to the central unit.

Quadcopter and ground robot will communicate wirelessly with the central unit. Especially from the quadcopter, this will insure the receiving of all necessary data even in case of losing the unit. Information transferred from quadcopter is typically the location of each detected suspected object and images from that location.

To guarantee the recipient of all data from the operated field with no losses, a balance between the safety of the central unit from any possible explosion and the quality of communication is the based-on factor to choose the location of the central unit for each area.

A web server application with a database server hosted on the central unit to do the following tasks:

- Receive data from quadcopter and to analyze it directly in the field.
- Upload the detected-mines information into digital map for future investigation in case of need.
- Send the updated digital map to mobile robot to locate the detected mines.
- Receive updated information from ground robot.

D. Digital Updating Map

Each landmine, projected on a digital-iCloud-Google-map, has the following properties: i) Identifier – Unique number assigned to every new landmine as long as there is no decision on the deletion of the landmine; ii) Position and depth of landmine t in the ground (x_r, y_r, z_r); iii) Dimension of new landmine object; and iv) Landmine type (anti-personal or anti-tank).

The cloud-environment used for: 1) Share information: the quadcopter send collected information to an external system (base station) running a Google Cloud Maps, thus

allowing human observers field situational awareness. 2) Mission parameters: The base station send collected data from quadcopter to the ground robot. The human interface allowed users to control the air and ground robots as desired by changing the individual parameters, authorizing, or altogether canceling the missions.

IV. EXPERIMENTAL RESULTS

Given a transmitter and a receiver as shown in Fig. 5, the efficient and simplest data acquisition method is to record a single scan of the subsurface, and consider the received signal. This received signal is termed an A-scan, and relates the signal amplitude with range. Example of a comparison between two A-scans (Landmine Recognition): one taken over a metallic cylindrical object and the other without the cylindrical object (i.e. the background) are shown in Fig. 9. Here the independent axis is time, which is related to the range, or in this case, target depth by the wave velocity ($v=d/t$), and the dependent axis is the amplitude of the received signals. The first A-scan (red graph) was recorded without anything-buried mines while the second A-scan (blue graph) was recorded above a mine target [10]-[12]. This comparison between A-scans, demonstrates how the presence of a target alters the received signal, and the direct communication that occurs between the antennas.
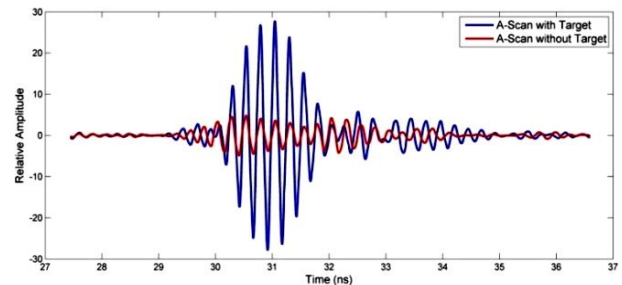

Fig. 9. Example of a comparison between two A-scans, one taken over a metallic mine object and the other without mine object.

V. CONCLUSION AND FUTURE WORK

Detection process of these mines usually takes a lot of time and effort and hence, it is usually neglected to the last step of priority levels. The GPR and Thermal image detectors automatically detect landmine; quadcopter updates GIS map and transfer the information about mine object to a central unit that will be responsible of investigating the received data; central base sends updated map to ground robot to start navigation.

GPR shows a promise, that is seems capable of accurately detect mines in various environments with few false alarms. GPR also suffers problems due to the presence of much clutter of components, that thermal image is used to reduce the clutter components in order to reduce the false alarm rates and increase probability of detection [13].

In the future, we will use new technology of detection of explosive objects on the ground and under the ground based on the operation of a mobile robotic complex using 3D-space representation. Moreover, the system is able to

work in the absence of GPS and Wi-Fi only based on its own data received by the quadcopter sensors and displayed on the simulator and a pre-prepared digital map [14].

REFERENCES

[1] B. Barkat, A. Zoubir, and C. Brown, "Application of time frequency techniques for the detection of anti-personal landmines," in *Proc. 10th IEEE Signal Processing Workshop*, 2000, pp. 594-597.

[2] M. Kurdi, A. Dadykin, I. Elzein, and M. Tatur, "Efficient navigation system of mobile robot with thermography image processing system and mapping of quadcopter," in *Proc. 4th Int. Conf. on Computer Science Computer Engineering and Education Technologies*, 2017, pp. 23-28.

[3] D. Daniels, "A review of GPR for landmine detection," *Sensing and Imaging: An International Journal*, vol. 7, no. 3, pp. 90-123, Sept. 2006.

[4] A. Mayordomo and A. Yarovoy, "Optimal background subtraction in GPR for humanitarian demining," presented at the 5th European Radar Conference, October, 2008.

[5] S. Sule and K. Paulson, "A comparison of bistatic and multistatic handheld Ground Penetrating Radar (GPR) antenna performance for landmine detection," in *Proc. IEEE Radar Conf.*, 2017, pp. 1211-1215.

[6] M. Kurdi, A. Dadykin, and I. Elzein, "Design and development of efficient guidance system using multi-functional robot with quadcopter," *Int. Journal of Electrical Energy*, vol. 5, no. 1, pp. 81-86, 2017.

[7] L. Cirillo, C. Brown, and A. Zoubir, "Polynomial phase signal based detection of buried landmines using ground penetrating radar," in *Proc. 11th IEEE Signal Processing Workshop*, 2011, pp 166-169.

[8] S. Kaya and U. M. Leloglu, "Buried and surface mine detection from thermal image time series," *IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing*, vol. 10, no. 10, pp. 4544-4552, 2017.

[9] L. Nam, L. Huang, X. Li, and J. F. Xu, "An approach for coverage path planning for UAVs," presented at 2016 IEEE 14th Int. Workshop on Advanced Motion Control, 2016.

[10] A. Zoubir, I. Chant, C. Brown, B. Barkat, and C. Abeynayake, "Signal processing techniques for landmine detection using impulse ground penetrating radar," *IEEE Sensors Journal*, vol. 2, no 1, pp. 41-51, Feb. 2001.

[11] D. Šipoš, P. Planinšič, and D. Gleich, "On drone ground penetrating radar for landmine detection," in *Proc. 1st Int. Conf. on Landmine: Detection, Clearance and Legislations*, 2017.

[12] A. S. Venkatachalam, X. Xu, D. Huston, and T. Xia, "Development of a new high speed dual-channel impulse ground penetrating radar," *IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing*, vol. 7, no. 3, pp. 755-756, 2014.

[13] I. Makki, R. Younes, C. Francis, T. Bianchi, and M. Zucchetti, "A survey of landmine detection using hyperspectral imaging," *ISPRS Journal of Photogrammetry and Remote Sensing*, vol. 124, pp. 40-53, 2017.

[14] L. Feng, Y. Weichao, L. Xiaoyang, S. Guangtong, and L. Jun, "Using high-resolution UAV-borne thermal infrared imagery to detect coal fires in Majiliang mine," *Remote Sensing Letters*, vol. 9, no. 1, pp. 71-80, 2018.

Moustafa M. Kurdi received the Bachelor of Engineering from Beirut. Currently, he is a director for Tyre campus and a coordinator of faculty of applied sciences, American University of Technology (Lebanon). He has more than 10 years of academic teaching experience in the fields of computer, software and networking engineering.

Mr. Kurdi is member of IEEE. His current research interests include robotics, computer vision, intelligent mobile robots, navigation system, image watermarking, and design automation.

Alex K. Dadykin was born in Minsk. Master degree, Ph.D. in Automated Control Systems from Minsk High Engineering Military School of anti-aircraft missile defense graduated with honors, in 1980 and 1989 respectively. In 1991, he was awarded the degree of Candidate of Technical Sciences (Soviet Union), and in 1999 was awarded the academic title of Associate Professor on "Informatics, control and computer engineering" (Republic of Belarus).

From 2001 to 2009, he served as Scientific Secretary of the Council for the defense of dissertations at the Military Academy of the Republic of Belarus.

Currently, he is an associate professor of the Department of Information Systems and Technology at the International Institute of Distance Education and a Chairman of the scientific meeting of the Belarusian National Technical University. He is the developer of four of the State educational standards for higher education for practice-oriented master's degree.

Dr. Dadykin in 2009 was elected Professor of the Academy of Military Sciences of the Russian Federation. He is the author of about seventy educational-methodical and scientific works, and he has five inventor's certificates. He is the Senior Member of IEDRC and the Member of IEEE. His main areas of research are in the field of system analysis, the development of learning management systems, and mobile robotic systems.

Imad A. Elzein is an electronics and computer engineer who obtained his undergraduate and graduate level degrees in electronics and computer engineering from Wayne State University, Michigan, USA in 2004. Currently, he is an Assistant Professor at the computer Science and Information Technology Department, School of Arts and Sciences, Lebanese International University (Lebanon).

Imad has more than 17 years of solid hands-on experience in the design, testing, and analysis of electronics, telecommunication, and networks engineering environments. His research of interests is in the fields of Renewable Energy, Network Design, and Robotics.
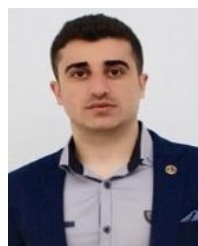
Ali K. Ibrahim received Diploma in Engineering - Intelligent Systems in 2017, and Master in automation and control of technological processes and production from Belarus National Technical University in 2018. His current research interests include automation, Intelligent Systems, robotics, and control of technological processes.