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Martin Jebens
International Committee of the Red Cross

Hideyuki Sawada, Ph.D.
Waseda University

Junjie Shen
Waseda University

Erik Tollefsen
International Committee of the Red Cross

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TO WHAT EXTENT COULD THE DEVELOPMENT OF AN AIRBORNE THERMAL-IMAGING DETECTION SYSTEM CONTRIBUTE TO ENHANCED DETECTION?

By Martin Jebens*, Hideyuki Sawada**, Ph.D., Junjie Shen**, and Erik Tollefsen*
*[ICRC] and **[Waseda University, Tokyo]

Over the past two decades, several initiatives that involved research and development on sensor and detection systems have failed to successfully integrate with clearance operations and have not been able to help affected states overcome the humanitarian challenges caused by weapon contamination. Though initial tests were promising, when faced with the reality of the field, the technology often indicates shortcomings.[1]

The terrain, dense vegetation, metal clutter, or other obstacles encountered in humanitarian mine action (HMA) pose challenges often greater than reliable target detection. Therefore, understanding the inherent challenges of a task is paramount when discussing the entry of new technologies into the field of HMA.[2]

Today, most technologies employed in survey or clearance operations fill one function only. The technology performs the intended function very well, but consequently separate intervention with different customized tools will be carried out in sequence, which often comes at the cost of safety, effectiveness, and cost-efficiency.[3]

Ideally, survey and clearance activities should be evidence-based and directed by field assessments and information analyses of a specific geographical area or a task such as a stretch of road or a community. New and developing technologies such as consumer market camera drones, affordable thermo-imaging cameras, and light detection and ranging (LiDAR) systems can be alternatives to other active or passive sensors and tools that can assist survey and clearance operators in establishing evidence of weapon contamination in a variety of scenarios. Such technologies could be elements in a toolbox approach that could help expedite activities without adding costs or impacting operator safety.

Thermal image of a stockmine taken from app. 10 m height. The FLIR Vue Pro sensors was used in an old mine field on the Danish west coast. The same type (not identical) of sensor was used by Nikulin et al. (2018) to detect landmines, and by Casana et al. (2017) to detect archeological objects. Test objects was German WWII stockmines. The beach environment was the same as when the mines were placed in 1944. Stockmines can be found throughout northern Africa. All test objects could be detected with no false alarm rate.

Figure 1. Thermal image of stockmine taken by FLIR Vue Pro.
All graphics courtesy of the authors.

The FLIR Lepton thermal sensor was tested in Geneva, Switzerland. This sensor is integrated in the Mavic 2 Enterprise drone. The resolution was 160 x 120. Many of the test objects could be identified from a 10 m height using this configuration, though only as a footprint and not with clear identification.

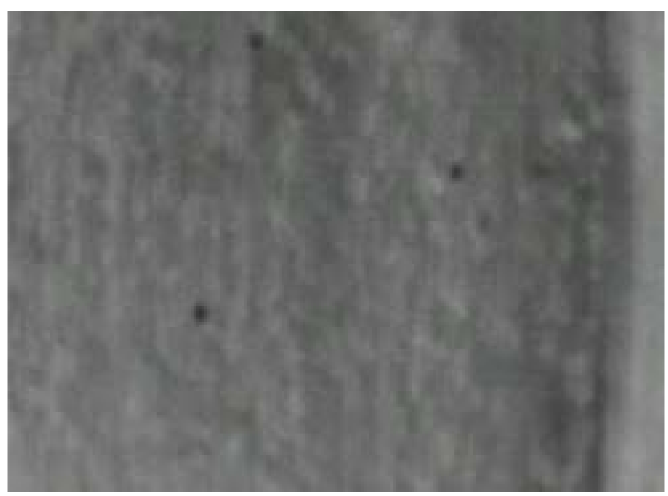


Figure 2. Thermal image metal objects taken by FLIR Lepton thermal sensor.

The InfReC Thermo FLEX F50 was used in a test in Japan. This sensor has a resolution of 240 x 240. The test objects on this image were a combination of wooden replicants of landmines, plastic, and metal objects. In this test the objects were placed both on bare soil and on vegetation. This dataset was used for deep learning (see later paragraphs).

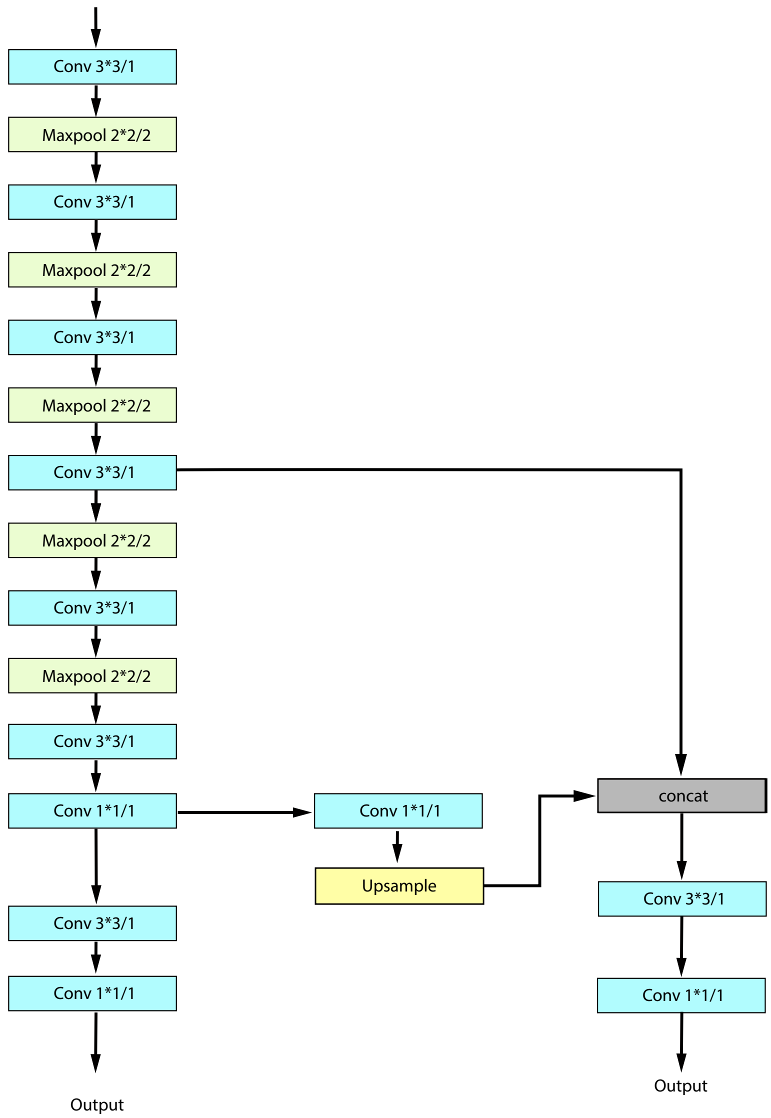


Figure 3. Architecture of tiny-YOLOV3.

The Gordian Knot in survey and clearance involves being able to reach sufficient confidence levels with the technologies and methods employed. As a result, the gold standard of today's operations remain manual operators equipped with metal detectors.

The paradox faced when introducing multi-sensor capability in survey and clearance operations is that while likely to increase the probability of detection (PoD), sensors—e.g., dual sensors combining ground-penetrating radar (GPR) and an electromagnetic interference (EMI) detector—will simultaneously raise the false alarm rate (FAR). This causes operators to have a lack of confidence in the reliability of the alarms observed. Simplified, this means that the increase in the PoD is improving the confidence, while the raised FAR is reducing the confidence levels of a multi-detector system. It is, however, believed that recent developments in deep learning technologies have the potential of helping us overcome this phenomenon. By developing a learning algorithm in the sensor system (thermal-imaging camera), an operator could help reduce the system's FAR on a day-to-day basis. The thermo-imaging technology discussed in this article is clearly not for all conditions, and national authorities and operators should aim to find the most permissible environment for each tool and detector, metal and heat-sensing alike.

In order to bring a functional and affordable concept to operators in the field, close cooperation between operators, research institutions, and manufacturers is vital. In partnership with Waseda University in Tokyo, Japan, the International Committee of the Red Cross (ICRC) has been developing a concept where a thermo-imaging camera mounted on a consumer drone has been used in trials to define a proof-of-concept for use in detection of explosive remnants of war (ERW), and to improve the confidence of detection by using deep learning. Two major Japanese technology consortiums have shown interest in the testing phase, and the test findings show promising results.

THERMAL SENSING

Remote sensing, the use of drones, and deep learning are technologies that are included in the discussions on how technology and innovation can improve humanitarian action and international peacekeeping. The 2016 Agenda for Humanity of the United Nations Secretary General states "that to deliver collective outcomes, the humanitarian sector must promote a strong focus on innovation."[4] These three technologies all have the potential to improve the capacity to assess needs and to monitor changes on the ground. Remote sensing is a relatively inexpensive and quick method to survey large areas of land on a variety of themes, with a low risk for the operators. Due to its relatively (depending on the platform chosen) low environmental footprint and impact on nature, remote-sensing applications support sustainable development and, therefore, are in line with the recommendations included in the Sustainable Development Goals (SDGs) and the Sendai Framework for Disaster Risk Reduction (SFDRR). Remote-sensing data can be collected using different platforms, e.g., satellites, airplanes, drones, or ground-based devices. This project focuses on using a drone-based solution even though combining satellite based and drone-based data can improve the quality of the result.

Thermal sensing is a type of remote sensing that has been tested and assessed as a method for detection of landmines (e.g., OZM-4 and PMD-6) but with no concluding results.[5,6,7] Compared to work done in the 1990s and early 2000s, recent advances in the development of sensors have identified a potential to use them for detection of small objects, as well as conventional (explosive) and chemical, biological, radiological, and nuclear (CBRN) weapons. The size of the object will be a function of the resolution of the thermal sensor and the flight height, hence a M42 explosive submunition can be identified from a flight height between 15 and 20 m.[8-12] Through a joint project, Waseda University and the ICRC wanted to better understand if recent technology developments in thermal sensing could contribute to enhancing operations in this sector and determine whether this technology

Figure 4. Drone with InfReC Thermo FLEX F50.

could eventually be applied to the broader humanitarian sector by assessing the following objective: To what extent could the development of an airborne thermal-imaging detection system contribute to enhance the pace of detection and disposal of mines and ERW?

The challenge in the project was to secure operability between an aerial platform, camera unit, and GPS recorder and to develop a deep-learning system capable of distinguishing patterns of landmines and weapons, including how to exclude homogenous and non-hazardous materials (metal or plastic). The first phase has recently been described successfully by Nikulin et al.[13] and DeSmet et al.,[14] but using deep learning to analyze the data will likely lower the FAR.

One major advantage in using thermal sensors compared to some other sensors is that it is passive. Hence, it only relies on the natural emission of heat energy from different objects. Therefore, thermal sensing is simply the process of converting heat energy into visible images. The principles behind thermal sensing of weapons are relatively simple: due to differences in composition, density, and moisture content, objects on and below the ground absorb, emit, transmit, and reflect thermal-infrared radiation at different rates.[15] Thermal energy is largely a surface phenomenon, and thermal cameras can't "see through" anything. Thermal sensing only measures the passive emission of heat energy from the surface of the nearest objects. However, an object's emission of heat energy can enable us to see buried objects if the soil is able to transfer the energy by conductivity. This will depend on the type of the soil, e.g., the size and shape of mineral grains, chemical composition, and water content. If the object is warmer or colder than the surrounding sediment, it can either cool or heat up the sediment in which it's placed. This can potentially be seen on the soil surface and be detected by the thermal sensor. Likewise, it is possible to detect reworked sediment. In general, heavy vegetation will lower the detection rate because the thermal sensor will receive the passive emission of heat energy from the vegetation covering the objects. However, the vegetation density can change above hidden or buried objects, due to the potential differences in the soil composition caused by the object itself or the rework of sediment. Using thermal sensors, it is possible to assess these differences in vegetation density, and potentially detect patters from landmines.

TESTING

Several tests were performed in Denmark, Japan, and Switzerland. Three different sensors were used during these tests, where the objective was not only the detection of weapons but for a wider use in the humanitarian sector, e.g., to detect human remains or mass burial sites, or to screen for epidemics in refugee camps. In addition, the sensors and drones chosen were commercial off-the-shelf products. Hence, if they can be used for non-technical surveys (NTS) and detection of weapons, it could be a faster, safer, and more cost-effective method. The sensors used included the FLIR Vue Pro, the InfReC Thermo FLEX F50, and the FLIR Lepton thermal sensor. All sensors were mounted on a drone, either a Phantom 3 Professional or the Mavic 2 Enterprise. Whereas sensors are manufactured with a wide range of technical specifications, the specific need should be assessed before choosing the sensor. For example, a thermal sensor used for analyzing the transfer of heat energy in the oceans will likely need a different configuration than the one used for detecting weapons, e.g., different resolution or focal width.

A detailed plan of the flight mission is essential for acquiring high-quality airborne data sets. This is because the user does not have direct control of the sensor, as in ground-based sensing. The flight plan must be based on the technical configuration of the thermal sensor and the aim of the analysis (e.g., size of target or detonation craters). An initial assessment of the area in which the thermal survey will take place is therefore necessary. The flight plan should relate to altitude, speed, frequency of images taken, overlap of images, time of day, and the targets under investigation. Consideration of these factors ensures coverage of the entire area, creation of high-resolution images, and recording of targets with a high enough number of pixels to be used for deep learning. Drones normally have a GPS system with an accuracy of approximately 2 m, depending on the number of satellites available at the time. A differential global positioning system can be used on some drones, which could decrease the accuracy to less than 20 cm.

Place	Time	Drone	Camera	Data Export
Denmark: Danish West Coast. Former WWII minefield	October, November and January (2019/2020)	Phantom 3 Professional	FLIR Sensor resolution: 640x480	16bit tiff
Japan: Tokyo	29 November 2019	Phantom 3 Professional	Nippon Avionics InfReC Thermo FLEX F5 Series Sensor resolution: 240x240	16bit tiff
Schweiz: Versoix	7 January 2020	Mavic 2 Enterprise	FLIR M2ED Thermal Camera Sensor resolution: 160x120	8bit

Table 1. Overview of the equipment used for testing in Japan, Switzerland, and Denmark.

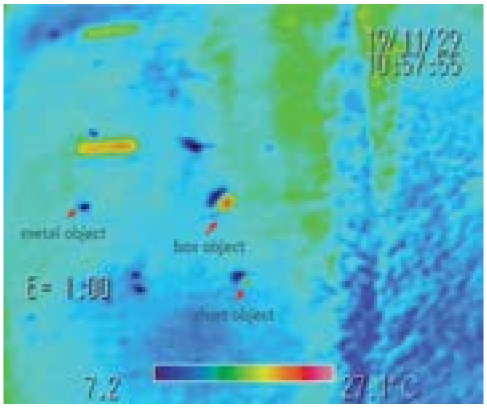


Figure 5a. Metal, box, short objects.

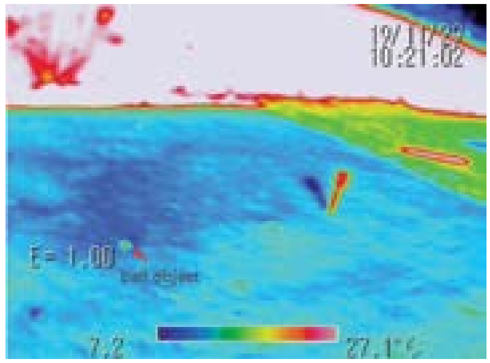


Figure 5b. Ball object.

Figure 5. Different objects in thermal images.

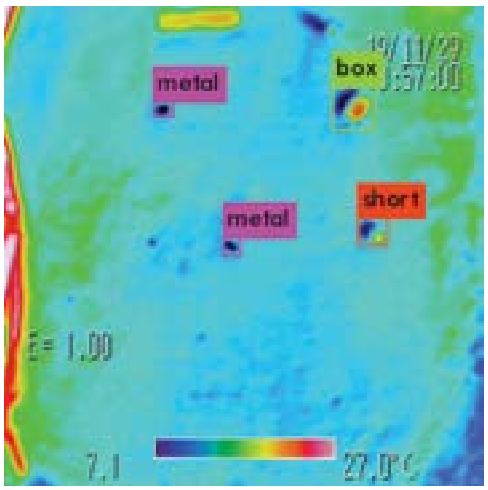


Figure 6a. Prediction result.

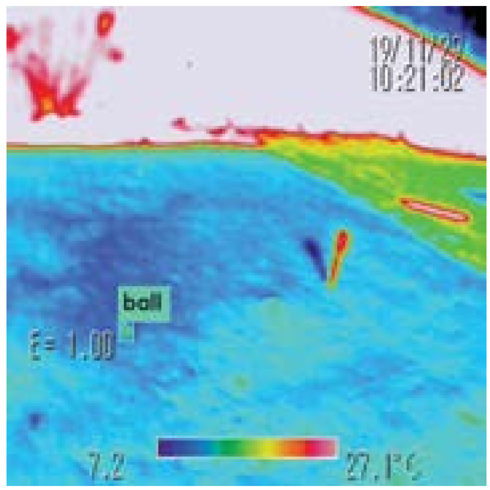


Figure 6b. Prediction result.

The FLIR Vue Pro and the InfReC Thermo FLEX F50 series enables users to capture raw, full-spectrum thermal imagery in 16-bit files that can be used for more advanced analyses. For some thermal sensors it is only possible to export data in 8-bit images. The 8-bit images do not offer the same range of values whereas identification of weapons is difficult. In addition, they do not contain information on the flight path. The FLIR Lepton thermal sensor belongs to the latter category (8-bit) and is therefore less capable of detecting weapons and cannot be used for deep learning. However, it can be advantageous in other types of assessments.

DEEP LEARNING

Deep learning is a technology that can greatly improve HMA. As an important branch of deep learning, object detection algorithms are constantly emerging. Tiny-YOLOV3, the abbreviation of "you only look once," is a popular real-time object detection algorithm. Compared with other objection detection algorithms (R-FCN, SSD), it has a fast detection speed and high accuracy.[16] Because of these advantages, tiny-YOLOV3 is used for detecting the mines in this experiment.

Tiny-YOLOV3 is a fully convolutional neural network, which includes many residual layers, and can help the neural network identify small objects. The tiny-YOLOv3 uses a total of 23 layers, which include the convolutional, maxpool, and residual layers. The architecture of tiny-YOLOV3 is shown in Figure 3.

The convolution layer is the core component of a convolutional neural network. Its role is usually to extract features from an input image. By changing the size of the kernel, the convolution layer can output images with different sizes. This provides researchers with the different features included in images, which in turn will be used for training the neural network.[17]

The maxpool layer downsamples the feature map. The function is to filter the features in the receptive field and extract the most representative features in the region, which can effectively reduce the output feature scale and then reduce the amount of parameters required by the model.[18]

The residual layer does not change the size of the input and output. It is used to deepen the network while controlling the propagation of the gradient, avoiding problems such as gradient dispersion and gradient explosion, and strengthening the training speed.

IMAGE DATA

The requirement for sensors in this project was to produce images having a high enough quality to be used for deep learning. The InfReC Thermo FLEX F50 thermal sensor was chosen because of its superior quality in providing thermal images. The drone system is shown in Figure 4. By using this system, high-quality thermal images were taken in Tokorozawa, Japan, and were used to train the neural network.

The experiment was mainly conducted on humid soil ground, using objects with different shapes and materials as detection targets. These included wooden objects in the shape of boxes and short sticks, plastic objects in the shape of balls, and metal objects placed on the ground. Two examples of thermal images taken by InfRec Thermo FLEX F50 are shown in Figure 5. The colors of particular materials are different in thermal images, which potentially enable researchers to detect various objects by using deep learning

TRAIN AND PREDICTION OF TINY-YOLOV3

As mentioned previously, tiny-YOLOV3 is a popular object detection algorithm with fast speed and high accuracy. This step can improve the resolution of the images, which results in the improvement of the recognition accuracy.

The learning rate was set to 0.001 at first. When the number of training iterations reached 400,000, the learning rate increased to 0.01. The learning rate also changes to 0.1 when the iterations reaches 450,000.

During the training process, each training batch is set to train 64 images. When the number of training batches reaches 500,200 the training process is terminated, and another parameter is related to the threshold. When the intersection over union (IOU) of the prediction grounding box and the ground truth box exceeds 0.5, this prediction value can be regarded as a good prediction. This can further improve the accuracy of the prediction.

After training the IR images, the prediction of the neural network is executed to extract objects. As shown in Figure 6, two metal objects, one box object, and one short object are properly detected. Dummy PMN-2 landmines were used as well. In this test, they were placed above ground. For this reason, the FAR was 0. Currently, testing is taking place on the detection of buried landmines.

NEXT STEPS

The evidence suggests that the method is appropriate in some environments (arid and semi-arid areas that can be encountered on a large scale, globally) and could improve NTS and detection of both buried and non-buried weapons. In addition, the use of thermal sensing is likely to benefit other humanitarian sectors. Several commercial companies in Japan, who also have identified this method as a worthwile technological advancement, have shown interest in using these methods in a wider humanitarian context. It is therefore the opinion of Waseda University and the ICRC Weapon Contamination Unit that the work should be taken into a second phase in which further testing should take place and also look into data fusion.

Data produced by remote sensors has, in the last decade, increased intensely. To cope with this collection of big-data, deep learning has been further developed.[19] Known types of remote sensing in HMA include GPR, gravimetry, electromagnetism, magnetism, etc. These individual data sets contain important information; however, combining the data sets from multiple sources via data fusion can improve the potential value and interpretation.[20,21] Ultimately, data fusion integrates the different information gathered from different sensors mounted on drones, satellites, or ground platforms hereby producing more detailed information. There are many applications for data fusion. Having been applied in sectors like defense and security, it is worth mentioning that data fusion can be used to further improve object detection, recognition, and identification.[22,23]

See endnotes page 71

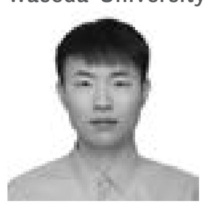
Martin Jebens
International Committee of the Red Cross

Martin Jebens is a consultant working for the Weapon Contamination Unit at the ICRC. Jebens works in the field of disaster risk management and sustainability. He has a strong focus on improved coordination, risk awareness, and planning to reduce risks and employs the SDG's and the Sendai Framework for Disaster Risk Reduction as guiding tools. Currently he is working on how technology and innovation can improve humanitarian action and international peacekeeping. He has a background in mine action and environmental management, disaster risk management, and exploration geology.

Hideyuki Sawada, Ph.D.
Waseda University

Hideyuki Sawada, Ph.D., is a Full Professor in the Department of Applied Physics, Faculty of Science and Engineering, Waseda University. He received his bachelor's of engineering, masters of engineering, and Ph.D. in applied physics from Waseda University. His current research interests include sound and image processing, neural networks, robotics, human interfaces, and tactile sensing and display. He is a member of IEEE, RSJ, IPSJ, IEICE, SICE, and JSME.

Junjie Shen
Waseda University



Junjie Shen is a master course student in the Department of Applied Physics, School of Advanced Science and Engineering, Waseda University. He received his bachelor's of engineering degree in communication engineering from Wuhan University of Technology in 2019. His current research interests include image processing and neural networks.

Erik Tollefsen
International Committee of the Red Cross

Erik Tollefsen is the Head of the Weapon Contamination Unit of the ICRC. Prior to working with the ICRC, he worked in the humanitarian mine action sector for nine years with the Geneva International Centre for Humanitarian Demining and seven years with Norwegian People's Aid. In the service of these organizations, Tollefsen carried out missions in Iraq, Iran, Afghanistan, Chile, Ukraine, Vietnam, Laos, Cambodia, Kosovo, Macedonia, Mongolia, Sri Lanka, Angola, and Israel, among others. Prior to this, Tollefsen served in the Norwegian Defence Forces as an Ammunition Technical Officer (ATO). In this capacity, he was posted to UNIFIL (Lebanon) and UNPROFOR (Bosnia and Herzegovina), during the conflict in the early 1990s as an Explosive Ordnance Disposal Officer.