An Innovative NXT Mobile Robot System for Landmine Detection

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Abstract
The current landmine detection technologies suffer many challenges on solving the humanitarian demining problem. Until now, detection and clearance in humanitarian demining very often relies on manual methods such as metal detector, as a primary procedure. The aim of this paper is to propose a multistage image processing methodology to detect the location of landmines in IR images. The methodology counts on the use of morphological image processing to detect the target mines. A database of images provided by the Royal Military Academy of Belgium was used to develop our results. The proposed MIP methodology was integrated with an NXT mobile robot, a smart N80 mobile phone and PC Server to test the developed software on a grid based environment. It was found that the proposed methodology and integrated system is very promising.

Keywords: Landmine detection, Morphological Operation, NXT Mobile Robot

1. Introduction
The development of demining technologies is a quite difficult and costly task. This is because of the wide range of terrains, which could be rocky, desert, beaches, muddy, river, forest, etc [1], [2]. It is important to mention that the climate conditions affect very much the available sensor technologies for landmine detection such as the Infrared (IR) technology [3]. IR technology is mostly affected by hot, humid, rainy, cold, windy conditions [4].

Humanitarian demining is a challenging process especially for the third world countries [5], [6]. To clear an area from mines, it requires that the removal process achieves a success ratio of 100%. The land should be free of mines with a high reliability and safety for human. Failure to do that will cost people life. The amount of time it takes to clear an area is less important than the safety of the clearance. Safety is with the highest importance. In military situation sometimes casualties are acceptable. This is not true in the case of civilians. We must also have a mechanism which results in no risks to those handling the demining task.

Thermal infrared cameras often used to detect landmines based on the assumption that landmines have different thermal properties than their surrounding soil. When an area is heated due to solar radiation, the landmines will warm up quicker than the soil. The soil above the landmine also warms up quickly.

The influence of the landmine on the temperature of the soil at surface level relates to the burial depth. This situation, where landmines give relatively warm spots at the surface cause what is called positive contrast. When an area is cooled, for instance some time after sunset, the situation is reversed. Landmines will cause cold spots at the surface and cause what is called negative contrast.

2. Promising Sensor Technology
In April 2001, a report was written to the Chairman, Subcommittee on Military Research and Development, Committee on Armed Services, House of Representatives entitled, "Landmine Detaction DoD’s Research Program Needs a Comprehensive Evaluation Strategy". The committee objective was to evaluate the DoD’s strategy for identifying the most promising land mine detection technologies. The report stated:

Improving DoD’s land mine detection capability is a challenging technological issue. Because of the threat that land mines pose to U.S. armed forces, you requested that we assess the abilities of competing technological options to address DoD’s mission needs for land mine detection. Specifically, our objectives were to determine whether DoD (1) employs an effective strategy for identifying and evaluating the most promising land mine detection technologies and (2) is investing in the most promising technologies to fully address mission needs.

The DoD search results show that: there are nine potentially promising technologies are funded by the DoD. They include: Acoustics/Seismic, Biosensors, Infrared/Multi-hyperspectral, LIDAR, Radar, Electromagnetic radiography, Passive millimeter wave, Terahertz imaging and X-ray fluorescence. These nine technologies proved to work in diverse environmental conditions with limited constraints related to soil types and water in soil.

Exploration of new technologies are being investigated to improve the reliability and speedup the detection operation, some of these technologies are Electromagnetic Induction Metal detectors (EMI) [7], Infrared Imaging, Ground-Penetrating Radar (GPR) [8], Acoustics, Thermal Neutron Activation (TNA), Photoacoustic Spectroscopy, Nu- clear Quadrupole Resonance (NQR), X-ray Tomography, Neutron Back-scattering, Biosensors, Commercial sniffers, etc.
2.1 Infrared (IR) Imaging

IR radiation constitutes a portion of the Electromagnetic Spectrum (EM) domain. The frequency band of the EM waves is between 100 MHz and 100 GHz [9]. This is a fairly high frequency band. IR spectrum span in the wavelengths domain of 75µm and 1mm [9]. It is known that EM radiation produces heat. IR radiation can respond to the heat based on the type of material. Using EM to get the emission response represents a good source of infrared radiation.

IR has been used widely for handling the landmine detection problem. One drawback of IR imaging is that IR relies highly on the environment at the moment of measurement and the type of soil in the background. Infrared methods detect variations in electromagnetic radiation reflected or emitted by either the mines surface or the soil and vegetation located above the buried landmines [1].

IR imaging requires sensitive cameras with sufficient resolution. This technology measures landmines at a maximum burial depth of 10-15 cm [9]. In general the strength of infrared signatures is independent of the landmine class, and varies through the day. It is a day to day dependent process depending on environmental conditions such as solar loading, precipitation, and wind.

3. The Proposed MIP Methodology

Our objective is to detect the location of landmines in Infrared images using a Multistage Image Processing (MIP) methodology (see Figure 1) and integrated mobile robot system. Number of image processing methodologies for landmine detection were proposed in [10], [11], [12]. The methodology starts by converting color image to gray scale. In the second stage, we select a suitable structuring element for performing morphological operation. We make image opening and closing on the gray scale image. In stage three, we check on the existence of objects in the image by selecting a suitable threshold level using our proposed methodology. By the end of this stage, we will be having a binary image with the detected object. In stage four, we label the connected components and use the Blob analysis technique to measure the properties for each labeled region [13].

3.1 Stage 1: Morphological Operations

Mathematical Morphology is a powerful tool for extracting useful components from an image. Morphological image processing technique was provided in [14] at the Ecole des Mines in Paris. The technique was introduced as a set-theoretic method for image analysis which could help in extracting geometrical structures from an image. Using morphology, we can provide boundaries of objects, their skeletons, and their convex hulls [15]. It was also found useful in pre- and post-processing phases of image processing, especially in edge thinning and pruning [16], [17].

Morphological image processing is a collection of techniques for digital image processing based on mathematical morphology [18]. Morphology Operations are useful in the representation and description of region shape since these techniques rely only on the relative ordering of pixel values, not on their numerical values, they are especially suited to the processing of binary images and gray scale images. In this stage, it is important to select an appropriate structure element for the opening and closing processes. It will significantly help in separating the object from the background. Since we are searching for a landmine shape, we decided to use a structuring element S of a disk-shape [19].

3.2 Stage 2: Thresholding

Threshold is an important technique for image segmentation which helps to identify or extract a target from an image. Threshold can significantly help in achieving this goal if a proper threshold-level is chosen. The appropriate level helps to classify the foreground and the background. Pixels that have a value of intensity level greater than the threshold level will be classified as a foreground. Increasing the threshold level reduces the number of false alarms, but also leads to a lower detection rate [20].

In the past, number of threshold techniques was proposed. In [21], image threshold method which combines various multi-scale and morphological features, including texture, shape and edge filtering by using genetic programming was presented. A faster version of Otsu’s method was proposed for improving the efficiency of computation for the optimal thresholds of an image [22]. A survey over image threshold techniques and quantitative performance evaluation was presented in [23], [24] and novel parametric and global image histogram threshold method was presented in [25].

The proposed threshold technique can be summarized in the following steps (see Figure 2):

- Obtain the image histogram.
- Locate the points of minimum gray scale level and consider it as local minimum. In the case of an image with one target (see Figure 2), the global minimum between the two peaks will be selected as the thresholding level. For an image with multiple minimum points (see Figure 3), we test all minimum levels till we locate our target.
- Remove all objects which have fewer than 100 pixels.
- Check if there is an object in the image, if not we tests another threshold level.

In Figure 3, we can see that the local minimum levels are located at the values 104, 122, 131, 153 and 159. Processing the image with the given threshold levels, we get the images provided in Figure 4 with landmine detected at level 159.

3.3 Stage 3: Feature Extraction

The binary large object (blob) is an area of connecting pixels with the same logical state. All pixels in an image that
Fig. 1: A flow chart of the Multistage Image Processing (MIP) methodology

Fig. 2: (a) Original image with one object (b) Image histogram (c) Processed image with the object detected

Fig. 3: Image histogram with multiple local minimum at levels 104, 122, 131, 153 and 159 of an IR image with landmine. All pixels that belong to a blob are in a foreground class. All other pixels are in a background class. In a binary image, pixels in the background have values equal to zero while every nonzero pixel is part of a binary object [26]. Blob analysis is used to get 1) edges locations; 2) center location; 3) number of pixels in an object [13].

Fig. 4: (a) Original image. Processed IR image with threshold levels (b)104 (c)122 (d)131 (e)153 (f)159
4. Difficulties of Landmine Detection Using Robotics

A cheap and fast solutions based mobile robot system is urgently needed especially for landmine applications. Mine-seeking robots are still in the premature development stages. Currently, mobile robot systems are not flexible for their intended missions or can provide cost effective solution for mine detection and removal. This is why there is a need for newly designed robotics hardware and software systems which can be attractive to their missions. Some of the difficulties associated with using robotics for landmine detection was described in [2], [27] and can be summarized as follows:

- Most robotic equipment is extremely expensive to build, expensive to run and expensive to maintain.
- The robotics technology in the countries were landmine is buried is very low. The complexity of the robots sometimes makes it difficult to excite the end users about it.
- Many problems arises when we deal with sensitive applications such as the landmine problem. This is because most of laboratory robots are not qualified for real detection and clearing environment (i.e. vegetation, sand and mud).
- A multi-robot system or gent of robots could provide a fast and efficient solution to the problem although the development of a control system to manage and activity for such systems is a complex task [28].

5. Basic Requirement of a Robot System

In [27] author stated that:

Before applying robotics technology for the mine clearance process, it is necessary to specify the basic requirements for a robot to have in order to achieve a better performance. These requirements include mechanisms, algorithms, functions and use.

These requirement was described in [27]. It can be itemized as follows:

- The robot should have a light weight not to active a landmine.
- The robot should have a simple design, flexible motion and highly reliable to accidents.
- The robot should be cheap to run, small, lightweight, and portable.
- The robot design should have adequate number of sensors to overcome obstacles and select a path.
- The robot should be able to recover problems which could happen during navigation and probing.
- The robot should be about to work in environment such as water, sand, temperature and humidity [29].
- The mechanical design of the robot should be simple for maintenance and repair.
- The robot high technology parts should be well protected.
- The robot power supply should enable the robot to operate for long period of time.
- The robot should have a remote control facility for tele-operation in landmine fields.

6. The Proposed Mobile Robot System

The demining process takes long time to accomplish and a minefield is one of the most dangerous regions. This paper proposes an integrated system which can speed up the process of mine detection and reduce risk than traditional manual methods for detection.

The proposed system relies on moving an NXT mobile robot to scan a minefield based on a developed grid environment of the mine field and detecting mines by using appropriate sensors attached to the mobile robot. The system developed a map of the area discovered, showing positions of located mines. The Proposed system consists of three devices as shown in Figure 5.

1) A PC Server is a Pentium 4 computer with a 512 RAM and support Wi-Fi connection. The PC Server is the brain for the whole system since it has the monitoring and the control system.
2) The LEGO NXT is the mobile robot which will be used to execute the mission. The NXT will hold the N80 mobile phone and navigate in the minefield.
3) N80 is a smart mobile phone device. N80 has an ARM-9 processor with clock rate of 220 MHz CPU, 18 MB RAM and Symbian OS v9.1 1. N80 include 3.0 Mega pixels camera and support for different type of wireless communications. They include (1) 3G network (384 kbps), (2) EDGE (286.8 kbps) (3) Bluetooth 2.0 and 4) WLAN 802.11b/g (See Figure 6).

The proposed system assumes we can have an IR camera to be carried on the mobile robot. We suggest the use of the 400DX IR camera to be attached to a PDA and used as a mobile wireless IR camera. The developed environment for our experimentation is shown in Figure 7. We considered the environment as a grid of steps each of which with a fixed selected size depending on the size of the mine field. A software system for the MIP was developed to apply the proposed MIP methodology. The user interface of the software is presented in Figure 8. The software was developed using MATLAB programming language.

7. Experimental Results

Our objective is to detect landmine from IR images using a proposed MIP methodology and integrated mobile robot

1Symbian OS is a proprietary operating system, designed for mobile devices, with associated libraries, user interface frameworks and reference implementations of common tools, produced by Symbian Ltd. It is a descendant of Psion's EPOC and runs exclusively on ARM processors [30].
系统。如我们所提到的，通常灰度值的雷管和土壤灰度值之间存在差异。

我们通过对Royal Military Academy of Belgium提供的真实图像进行实验。MWIR数据库提供了136个IR图像，用于沙子和砾石土壤[31]。这些图像是在1998年4月1日、2日和3日，使用中波长红外摄像机-AGEMA（3µm-5µm）收集的。

在图9和图10中，我们展示了带有雷管的原始IR图像，以及图像的对应直方图和使用我们提出的MIP方法处理后的图像。这两次图像分别在13:08和22:04，共享一个沙土背景。

我们对具有砾石土壤背景的两个图像应用了我们提出的算法。图11和图12展示了结果。两次图像分别在12:18和22:04，共享一个地球环境。通过将结果与[32]提供的结果进行比较，位置的验证成功。所选的阈值合适。这意味着所提出的算法在日间和傍晚图像中都工作得很好。
Fig. 9: (a) Original IR image on a sand soil taken at a time 13:08 (b) Image histogram (c) Processed image with mine detected

Fig. 10: (a) Original IR image on a sand soil taken at a time 22:04 (b) Image histogram (c) Processed image with mine detected

Fig. 11: (a) Original IR image on a gravel soil taken at a time 12:18 (b) Image histogram (c) Processed image with mine detected

Fig. 12: (a) Original IR image on a gravel soil taken at a time 21:19 (b) Image histogram (c) Processed image with mine detected
8. Conclusions
In this paper, we provided a multi-stage image processing technique which uses morphological image processing to locate landmine in infrared image. The proposed MIP methodology was integrated with a mobile robot system for testing purposes. The process starts by converting color image to gray scale, select suitable structuring element for performing morphological operation, pick up a suitable threshold level to locate the landmine object, produce a binary image with the detected object. Finally, the target is labeled and located. The developed results were verified according to [32] with correct the correct mine locations detected. The developed results show that this system can be expanded with appropriate hardware facility to work in real landmine fields.

References
Biography

Alaa F. Sheta received his B.E., M.Sc. degrees in Electronics and Communication Engineering from the Faculty of Engineering, Cairo University in 1988 and 1994, respectively. He received his Ph.D. degree from the Computer Science Department, School of Information Technology and Engineering, George Mason University, Fairfax, VA, USA in 1997. He was promoted to professorship in 2008. Currently, Prof. Sheta is a faculty member with the Computer Science Department, The World Islamic Sciences and Education (WISE) University, Amman, Jordan. He is on leave from the Computers and Systems Department, Electronics Research Institute (ERI), Cairo, Egypt. He published over 80 papers, book chapters and two books in the area of image processing and evolutionary computations. He has been an invited speaker in number of national and international conferences. Prof. Sheta is a member of the IEEE Evolutionary Computations, ACM and ISAI societies. He is also the Vice President of the Arab Computer Society (ACS). His research interests include Evolutionary Computation, Modeling and Simulation of Dynamical Nonlinear Systems, Image Processing, Robotics, Swarm Intelligence, Automatic Control, Fuzzy Logic, Neural Networks and Software Reliability Modeling.