УДК 614.846.6

MOUSTAFA M. KURDI

EFFECT OF VIEWING ANGLE OF IR THERMOGRAPHY CAMERA FOR THE DETECTION OF LANDMINE

Belarusian National Technical University

The detection and recognition of sub-surface buried objects, such landmines, with variable characteristics may be extremely difficult. Infrared (IR) thermography, which is widely employed in the detection of discontinuities in materials and structures, would be in principle suitable also for this kind of application. The issue in this case appears to be the presence of excessive levels of background noise, whose modelling is difficult, in that it results from a number of factors e.g., moisture content, presence of vegetation, and variation of solar radiation at topsoil level. In recent years, a number of studies have tried to overcome these limitations and improve the reliability of this method, using filtering and automatic pattern recognition techniques, specific for the detection of buried objects. This work is aimed at revising and commenting the most recent experiences in this application of IR thermography. The article considers the possibility of using an IR thermal imaging camera attached to a multifunctional quadrocopter in order to improve the reliability of detection of ground and buried explosive objects.

Keywords. *Image Processing, Infrared Thermography, Mobile Robot, Multifunctional Quadcopter, Wireless Communication.*

I. INTRODUCTION

Infrared thermal imaging, also often briefly called thermography, is a very rapidly evolving field in science as well as industry owing to the enormous progress made in the last two decades in micro system technologies of IR detector design, electronics, and computer science. Thermography nowadays is applied in research and development as well as in a variety of different fields in industry such as non–destructive testing, condition monitoring, and predictive maintenance, reducing energy costs of processes and buildings, detection of gaseous species, and many more [1]. IR thermal imaging has also been widely used for landmine detection. The detection of landmines and clearance is still a time consuming and unsafe task. Additionally, efficient and accurate detection of buried mines is still a challenging problem [2].

There is no universal technique capable of detecting landmines in all conditions. Infrared thermography is a promising technique in the detection and discrimination of the landmines. The detection principle is based on the variation of the ground temperature due to the presence of buried or surface landmines. Sand and mines have different thermal properties and this difference can be observed on the surface through the thermal sensors. Since thermal property is a dynamic behavior driven by radiation from the external heating system, it can change with the temperature in a few minutes and it can be observed better in thermal image time series than a single image.

Active thermography technique can be applied to enhance the contrast between the possible targets and the background. This contrast stems from the difference in radiant characteristics between the landmines and the background soil. Landmines are explosive devices hidden just below the surface designed to be detonated by contact of people or vehicles, as they pass over or near them.

We are designing and developing an intelligent system of unmanned air vehicle and unmanned ground vehicle named Quadcopter Mobile Robotic System (QMRS) [3], as shown in Fig. 1, which performs several operations, as a movement in specified direction, detect landmine by quadcopter, project the landmine by GIS into digital map and navigate the projected landmine on digital map by mobile robot.

II. EMISSIVITY

Emissivity value, which is one of these characteristics, plays a significant role in the determination of correct temperature of an object surface [4]. The source of uncertainty in temperature measurement with the infrared camera can be list-

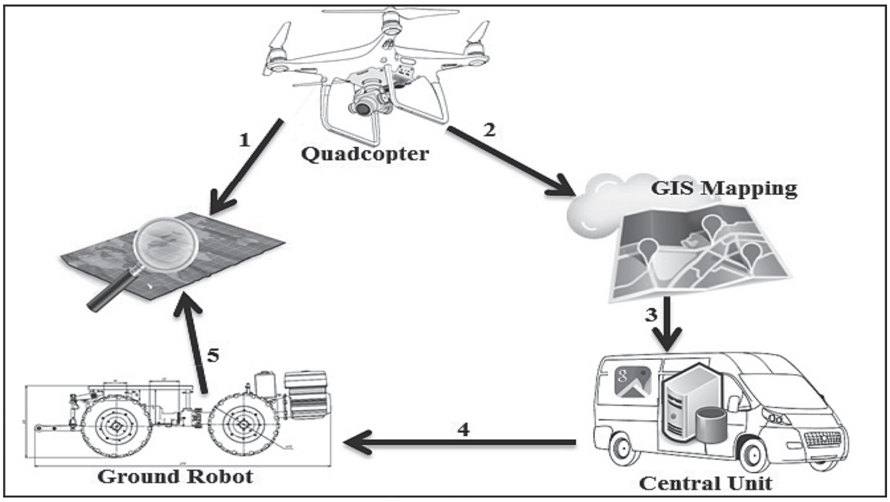


Fig. 1. General Architecture of the Proposed System

ed as followings: emissivity ($\mathcal{E}$) of objects, infrared detector-to-surface angle and distance. Those are mainstream technical factors for an accurate infrared thermographic measurement.

The emissivity is a measure of the efficiency of a surface to emit thermal energy relative to a perfect blackbody source, it directly scales the intensity of the thermal emission, and all real values are less than 1.0. The emissivity may be highly dependent on the surface morphology, roughness, oxidation, spectral wavelength, temperature and view angle. A measurement that does not account for the real emissivity of a surface will appear «colder» than it actually is. For agricultural applications, many organic materials and materials with very rough surfaces have emissivity values approaching unity. For other applications, including power line and solar cell inspection, the surface might be a highly polished glass or metal, both of which can have much lower emissivity values. As a reference, the table demonstrates the wide range of emissivity values that may be encountered in radiometric applications.

Emissivity values for common materials

Material Description	Emissivity
Asphalt	0.90 to 0.98
Concrete	0.92
Soil, dry	0.90
Soil, wet	0.95
Wood	0.90
Water	0.92 to 0.96
Snow	0.83
Skin, human	0.98
Aluminum, polished	0.04 to 0.06
Steel, rusty	0.69
Steel, stainless	0.16 to 0.45

III.BACKGROUND

A. Mine Problem

Landmines are explosive devices hidden just below the surface designed to be detonated by contact of people or vehicles, as they pass over or near them. Landmines contaminate still 60 countries around the world and thousands of people continue living with a risk of losing their life or limb. In addition, emplaced landmines hinder the cultivation of large productive areas. Besides, they maintain a sense of insecurity long after conflicts end, delay peace processes and impede countries' development for years [5].

Because of these horrendous effects, a lot of research and technological developments are needed to solve the detection and clearing of landmines problem. One widely searched solution for this problem is IR thermal imaging.

B. Thermal imaging

Each material shows a characteristic thermal response to a given stimulus, also known as the thermal signature. Thus, the cooling or heating process affects buried objects and the surrounding soil in a different way. This difference is because the mines are better insulators than the soil. The general concept of using infrared thermography for mine detection is because mines may have different thermal properties from the surrounding material [6] as shown in Fig. 2. Thermal imaging devices measure the emissivity of surfaces in an area at various temperature ranges.

Uniquely, IR can work in either way, actively or passively. It can work by accepting only the natural radiation from the object called as passive ther-

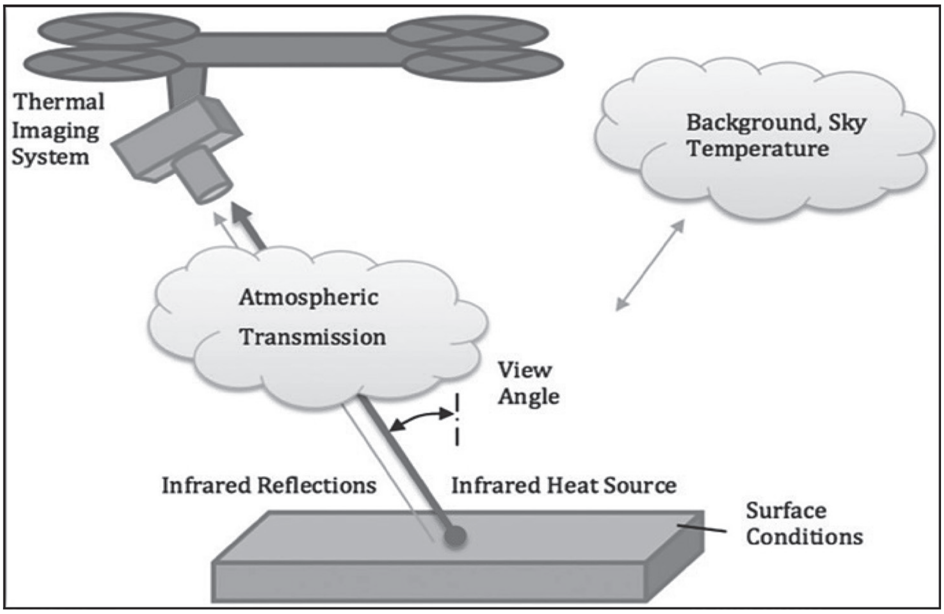


Fig. 2. Thermal Imaging System

mography, or it can provide an extra heat source and receive the artificial radiation created by that heat source dubbed as active thermography [7].

Most thermal detection concepts involve single snapshot of the region of interest. The soil over a mine has different thermal dynamics than homogeneous soil and, as a result, a time sequence of images can often produce better detection than a single image [8].

Principal factors is to be considered in the detection of buried objects using IR thermography:

1. Soil surface conditions (Presence of vegetation and/or soil surface coverage (cluttering), Homogeneity/inhomogeneity of soil, Collaboration/non-collaboration of soil);
2. Soil nature (Chemical composition, Granulometry, Moisture content);
3. Climatic variations (Temperature/humidity cycles, day-night);
4. Buried object characteristics (Geometry, Dimension, Materials);
5. Buried object position (Depth, Orientation);
6. Thermal excitation (Natural – solar, Long pulse – microwave, Short pulse: UV, IR, normal lighting).

IV. PROPOSED SYTEM

Quadcopter Mobile Robotic System is an efficient system for detection landmines. The system consists of ground robot Belarus-132N, ground-penetrating radar and thermal camera attached to multi-functional quadcopter.

QMRS performs several operations, as a movement in specified direction, detect landmine by quadcopter, project the landmine by GIS into digital map and traverse the projected landmine on digital map by mobile robot. 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-based robot developed and manufactured as a result of cooperation of scientific and industrial enterprises of Belarus. It is a 4-wheeled robot with dimensions 120 cm length, 120 cm width, 180cm height, and 500 kg weight. It comprises of serial frame of tractor Be-

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

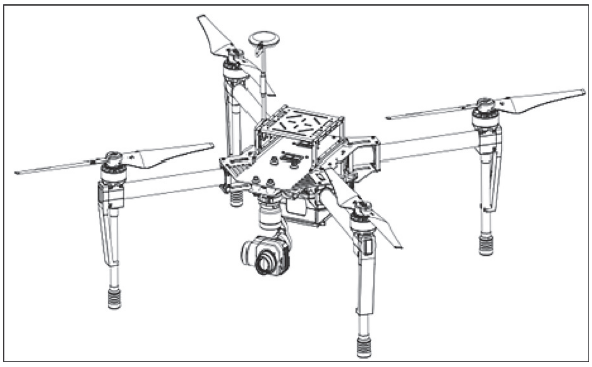


Fig. 4. General Scheme of multi-functional quadcopter

larus-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.

It has a server with geographic information system provided from base-station with a landmines marked digital map for the site location; GPS-receiver, which determines current coordinates on the map. Data from the GPS-receiver is continually refreshed and connected to a digital map. 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.

B. Multi-functional Quadcopter

A quadcopter or Unmanned Aerial Vehicle is a 4-rotor helicopter that use 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.

The components of Quadcopter are frame F450, EMAP Simon 30A Electronic Speed Controller, EMAX-MT-2213 motor, Flight controller KK v2.0 board, 2.4GHz receiver, transmitter, MPU9255-3 axis gyroscope – 3 axis accelerometer – 3 axis compass, single-board Raspberry Zero W, Wi-Fi adapter, thermal camera, universal GPIO I/O ports, Saitek X52 to ensure full-duplex communication, 3-cell 2200mAh 25C LiPo Battery, and thermal camera (Fig. 4).

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.

V. EXPERIMENTAL RESULTS

Three types of experiments performed at the viewing angles of 90°, 60° and –60° as it is shown in Fig. 5 during three days. The acquired thermal images are stored in a personal computer. The

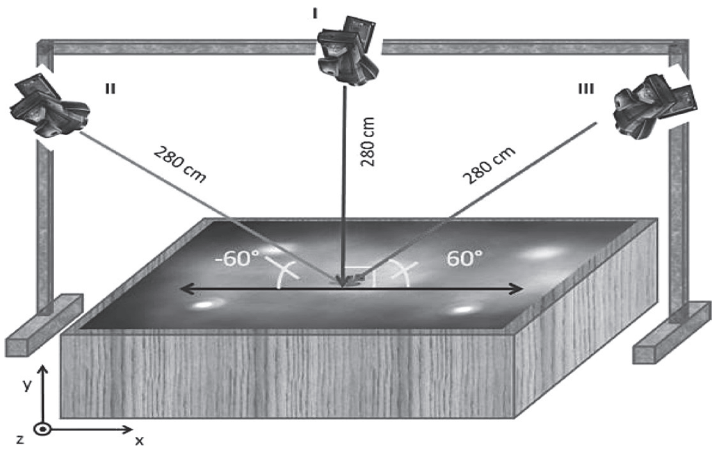
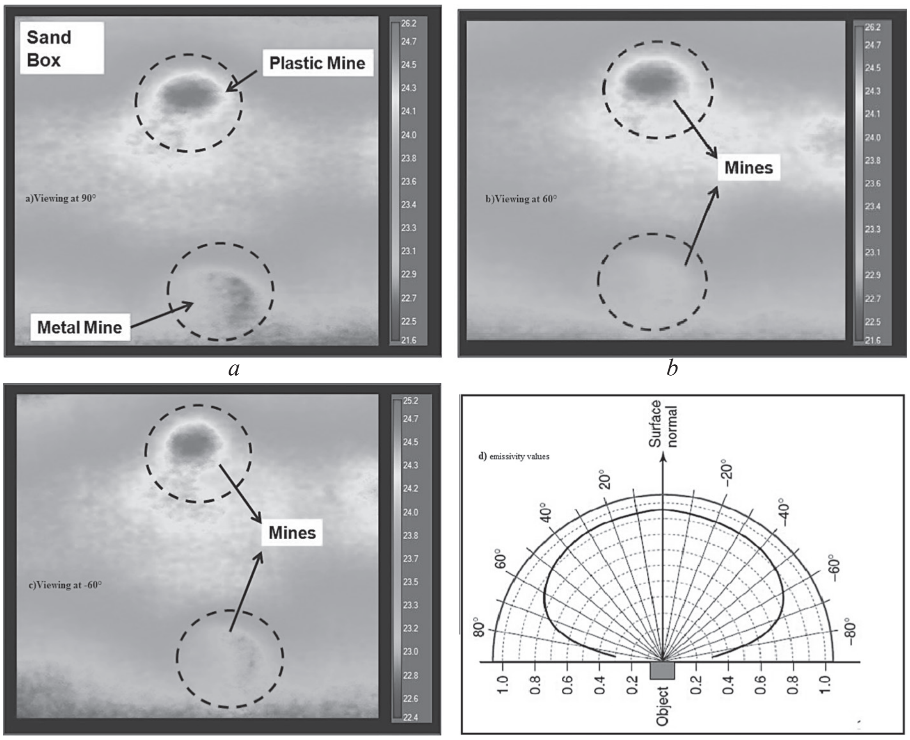


Fig. 5. IR image sequence of a minefield; images taken at (*a*) 90°, (*b*) 60° and (*c*) –60°



a *b*

c *d*

Fig. 6. The mines locations; images taken at (*a*) 90°, (*b*) 60° and (*c*) –60°; (*d*) emissivity values at different angles

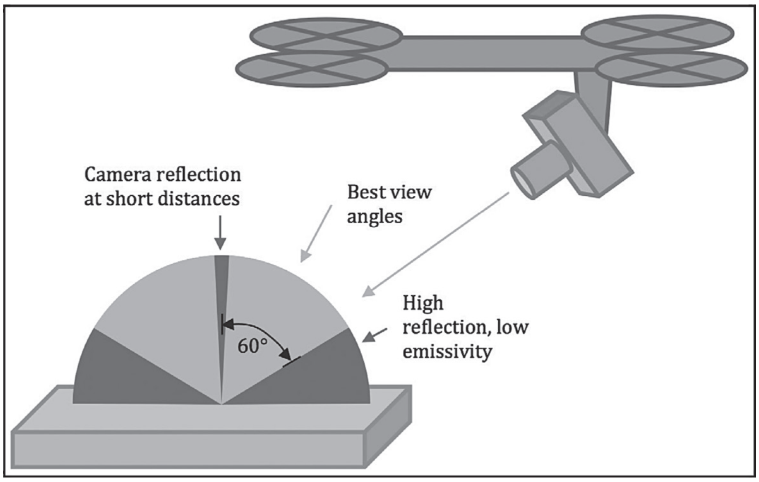


Fig. 7. Thermal temperature measurements should avoid straight-on measurements to reduce direct camera reflection and avoid oblique angles to reduce overall reflection

model mines were buried into a depth of 20 cm beneath the sand surface. Sequence of images was captured with FLIR T-650 SC camera placed in 280 cm distance from the detection area. Size of image is 480×640 pixels.

The temperature effect of the presence of the mine on the sand surface at each angles are clearly shown in Fig. 6 (*a*, *b*, and *c*). The surface temperature of the sand above plastic mine was higher than the surface temperature of the sand beside mine. However, the situation was just opposite when it comes to metallic mine. The hot and cold surface spots caused by the energy reflected from the surface over mines generally became apparent within a similar period [9].

The results showed that the amplitude of the surface temperature change above the mine was much greater than that on the surface beside it: this was caused by the heating method. In all tests, the locations of the mines were identified using FLIR T-650 SC thermal camera and Research IR Program. The evolution of the «hot spot» and «cold spot» above the mines can be observed from the results shown in Fig. 6.

Our experiments confirmed that emissivity nearly remains constant from 60° to –60° degrees from the horizontal. These results were in agreement with what reported in Infrared Thermal Imaging Fundamentals, which explains the influence of viewing angle on emissivity of a surface. However, Fig. 6 (*d*) demonstrates an effect that fortunately holds for nearly all practically important surfaces: the emissivity is nearly constant from the normal direction 0° to at least 40 or 45° [10].

Care must be taken not make measurements at exceedingly oblique angles because reflectivity degrades based on view angle. Alternatively, a very close range and straight-on measurements can result in the camera viewing a reflection of itself and result in inaccurate measurements. Figure 7, illustrates the view angle challenges for radiometric temperature measurements and recommends making measurements less than 60° normal to the surface.

CONCLUSION

In our study, the effect of viewing angle is investigated by combining the analysis of temporal IR image sequences, showing the dynamic scene behavior during time variant heating by an infrared heater. The results show that different viewing angles (for 90°, 60° and –60°) have relatively little effect on the temperature at the surface. The emissivity is approximately constant at the viewing angles between 60° and –60°.

Experiments have shown that active thermography has strong positive effect on thermal signature in a short time. It can be especially useful in military tasks.

The thermal properties of the mine itself can play a significant role according to the thermal signatures. In addition, it is shown that 60 minutes duration is enough to produce thermal signatures for buried mines at a depth of 2cm from the surface with active thermography.

REFERENCES

1. **F. Cremer, N. T. Th`anh, L. Yang, and H. Sahli,** «Stand-off thermal IR minefield survey, system concept and experimental results», Proceedings of SPIE 5794, Detection and Remediation Technologies for Mine and Minelike Targets X, pages 209–220, 2005.

2. **S. Gutman and J. Ha.,** «Identifiability of piecewise constant conductivity in a heat conduction process», SIAM J. Control Optim., 46(2):694–713, 2007.

3. **M. Kurdi, A. Dadykin, I. Elzein, M. Tatur,** «Efficient Navigation System of Mobile Robot With Thermography Image Processing System And Mapping of Quadcopter», International Journal of Digital Information and Wireless Communications (IJDIWC), pp. 90–95, Vol. 8, No. 2, June 2018.

4. **T. Nunak, K. Rakrueangdet, N. Nunak, T. Suesut,** «Thermal image resolution on angular emissivity measurements using infrared thermography», Proceedings of the International MultiConference of Engineers and Computer Scientists, 2015.

5. **P. L´opez,** «Detection of Landmines from Measured Infrared Images using Thermal Modelling of the Soil», PhD Thesis, University of Santiago de Compostela, 2003. 26

6. **C. P. Lee,** «Landmine detection techniques using multiple sensors», M. Sc. Thesis, Electrical and Computer Engineering the University of Tennessee, Knoxville, 2004.

7. **N. T. Th`anh,** «Infrared Thermography for the Detection and Characterization of Buried Objects», PhD Thesis, Vrije Universiteit Brussel, Brussels, Belgium, 2007.

8. **J. MacDonald, J. Lockwood, J. McFee, T. Altshuler,** «Infrared/Hyperspectral Methods,» in Alternatives for Landmine Detection», Rand, 93–110, 2003.

9. **A. Muscio and M. A. Corticelli,** «Land mine detection by infrared thermography: reduction of size and duration of the experiments», IEEE Transactions on Geoscience and Remote Sensing, 42 (9): 1955–1964, 2004.

10. **M. Vollmer, K. P. Mollmann,** «Infrared thermal imaging fundamentals, research and applications», WILEY-VCH Verlag GmbH & Co., Weinheim, GERMANY, 2010.

Поступила	*После доработки*	*Принята к печати*
06.06.2018	*01.09.2018*	*31.08.2018*

Moustafa M. Kurdi

ВЛИЯНИЕ УГЛА НАБЛЮДЕНИЯ ИК ТЕПЛОВИЗИОННОЙ КАМЕРЫ НА ОБНАРУЖЕНИЕ НАЗЕМНЫХ МИН

Белорусский национальный технический университет, mostafa.alkirdi@aut.edu

Обнаружение и распознавание взрывоопасных объектов, находящихся на поверхности или на небольшой глубине под поверхностью, таких, как наземные мины с различными характеристиками, может быть чрезвычайно трудным делом. Инфракрасная (ИК) термография, которая широко используется для обнаружения разрывов в материалах *и структурах, в принципе подходит и для такого рода применения. Проблема в данном случае, как представляется, заключается в наличии чрезмерных уровней фонового шума, моделирование которого сопряжено с трудностями, поскольку оно обусловлено рядом факторов, например, влажностью, присутствием растительности и изменением солнечной радиации на уровне верхнего слоя почвы. В последние годы в ряде исследований были сделаны попытки преодолеть эти ограничения и повысить надежность обнаружения, используя методы фильтрации и автоматического распознавания образов, характерные для нахождения захороненных объектов. Эта работа направлена на пересмотр и комментирование самого последнего опыта в этом применении ИК-термографии. В статье рассмотрена возможность использования ИК тепловизионной камеры, прикрепленной к многофункциональному квадрокоптеру, с целью повышения надежности обнаружения наземных и погребенных взрывоопасных объектов.*

Ключевые слова. *Беспроводная связь, инфракрасная термография, многофункциональный квадрокоптер, мобильный робот, обработка изображений.*

Moustafa M. Kurdi received the BE degree from the Department of Computer Engineering, Beirut Arab University, Lebanon, in 2002, and the MBA degree from the Department of Business Management, Lebanese International University at Lebanon, in 2010. He is presently a Ph. D. candidate at the Electrical and Computer Engineering Department of Belarusian National Technical University, studying control, system analysis and data processing.

Currently, he is 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.