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IMAGE PROCESSING IN MILITARY SECURITY AND DEFENSE PROBLEMS

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ABSTRACT

In this conference paper, we present image-processing applications for military purposes. We show many possible applications for security and defense problems in the military linked to digital image analysis. We discuss object detection, weapon detection, detection and segmentation of important military points, objects and targets in Earth maps and SAR data. Furthermore, we implemented our own software based on mathematical discrete algorithms, where we analyze SAR data for detection of objects, regions, landscape regions even military objects. We are using mathematical models for segmentation, and we did own implementation into computer software for image segmentation. This way, military officers and leaders can analyze visual problems and consider the danger of concrete objects in images. Military administrations can use this kind of information for safety and defense tactic decisions.

Keywords: image analyses, digital data, SAR data, military security

INTRODUCTION

Digital signal processing (DSP) is the use of mathematical techniques to manipulate, analyze, and transform signals, such as sounds, images, and videos. DSP has many applications in image processing, which is the field of computer science that deals with enhancing, compressing, restoring, and interpreting digital images.

Due to its many applications, including object recognition and target tracking, image processing technology has been used by the military more and more recently. The development of artificial intelligence (AI) and machine learning, coupled with the increasing accessibility of high-definition imaging equipment, is being leveraged by armed forces worldwide to enhance operational efficiency, information gathering, and situational awareness.

By using computer vision, the military can securely derive critical information and data, make smart decisions, and act more agility to protect national security. Because technology is always changing, it is important to know what is new in computer vision and how it can be used in the defense and security business.

The role of image and video processing in army and military stuff: Helicopters, drones and other military vehicles use vision systems enabled by rugged embedded hardware to operate in degraded visual environments.

At the tactical level even sensing of the enemy minefields may be done by satellites. On the strategic level, verification of the arms control agreements strongly depends on image processing to identify and count missile silos from reconnaissance images. The first step in remote sensing is data acquisition. The study of gathering data about the surface of the Earth without going in direct contact with it is known as remote sensing. This is accomplished by processing, interpreting, and using the energy that is sensed, recorded, and reflected or emitted. Using sophisticated cameras on satellites and aircraft to capture pictures of vast swaths of the

Earth's surface or the temperature variations in the oceans are a couple of instances of remote sensing.

Noise and other inadequacies from the onboard sensors or radiative transfer mechanisms may be present in remote sensed data. As a result, we frequently use additional preprocessing methods to address these issues. Image processing is the broad term used to describe these many processing methods.

The phrase "image processing" refers to a broad range of processes that are applied to an image to produce an improved image or to analyze an image and extract usable information. This kind of signal processing uses a picture as the input, and the output could be the image itself or some traits or features connected to it. Medical imaging, machine vision, robotics, computer-generated imagery (CGI), face detection, optical character recognition, fingerprint detection, surveillance, videoconferencing, and satellite data analysis are a few of the significant fields in which

Image processing is used in science and technology. Image processing allows drones to monitor traffic and environmental conditions to take high-resolution, real-time pictures and movies. Knowing which catastrophe-affected areas the authorities should concentrate on might assist save lives by enabling them to rapidly access and safely rescue persons who are stranded in the event of a natural disaster or other calamity, such as a fire, earthquake, flood, or other disaster. Real-time image processing techniques can even facilitate coordination and progress tracking during such rescue efforts. Digital image processing is the use of algorithms and mathematical models to process and analyze digital images. The goal of digital image processing is to enhance the quality of images, extract meaningful information from images, and automate image-based tasks. We can consider more items of image processing.: Image Acquisition: the image is captured by a sensor, Image Enhancement, Image Restoration, Color Image Processing, Wavelets, Compression, Morphological Processing, Image Segmentation.

In this paper we present some concrete applications of image processing for military usage linked to security and defense problems in the military. We bring examples as well as some concrete results. Based on mathematical algorithms we implemented and created our own software in C++ for segmentation of object, which can be used for segmentation of digital SAR data as well as digital data, as cracks in sidewalks, buildings and materials.

1 APLICATIONS OF IMAGE PROCESSING IN FEW AREAS AND NEEDS IN THE MILITARY

Digital image processing has been widely used in the defense and security industries for tasks like automatic/aided target recognition, vehicle navigation, missile guidance, wide area surveillance, and small target detection tracking. Also management tasks are involved in the matter of safety and defense (Gubáš, 2015).

Reducing the burden of human analysts in military and security applications is one objective of an image processing strategy, as the amount of image data being gathered keeps growing. Researchers studying image processing also aim to create methods and algorithms that will greatly facilitate the creation of completely autonomous systems that can make judgments and take actions based on information from all their sensors. This is a second, more difficult objective, see more in (Du – Ives - VAN Nevel, 2010).

Target tracking by means of image processing is one of the many uses of this technology. Image processing techniques are used to collect valuable information about the Earth's surface from a distance. Terrain mapping, environmental monitoring, and detection of camouflage and cover-up tactics used by adversaries are some of the military uses of remote sensing. These capabilities allow military planners to gain valuable insights into the operational environment and plan missions with greater precision, thanks to these capabilities. The importance of image processing in defense systems is growing due to numerous factors, such as the necessity of autonomous operation and the necessity of utilizing the outputs from a variety of sophisticated sensors. Data is becoming a powerful tool for resource exploitation and management. Methods for analyzing the new kinds of information are being developed. Satellites may be used to detect enemy minefields at the tactical level. Image processing is used to identify and count missile silos from reconnaissance images on the strategic level.

Recognizing objects: The military uses image processing technology for object recognition. AI algorithms can identify and classify objects of interest in real-time by analyzing images captured by various sensors such as drones, satellites, and surveillance cameras. Military personnel can quickly assess the battlefield environment and identify potential threats or targets with vehicles, personnel, weapons, and infrastructure.

Tracking of specific goal: Image processing technology is also essential in target tracking, enabling military forces to monitor enemy asset movements and maintain continuous surveillance over valuable targets. Tracking algorithms can forecast the path, speed, and direction of moving objects by examining sequential images and identifying essential characteristics, offering instant updates to commanders and operators.

Intelligence gathered on the battlefield: Image processing technology helps to extract useful intelligence from vast amounts of visual data. Through the examination of images for different patterns, irregularities, and developments, military analysts can detect possible dangers, evaluate enemy motives, and reveal concealed networks or buildings. This intelligence has the ability to provide guidance for decision-making at every level of command and aid in mission planning, execution, and post-mission analysis.

Enhanced Situational Awareness: Improved understanding of the current environment: One of the key advantages of image processing technology in the military is its capability to improve awareness of the situation on the battlefield. By giving instantaneous access to visual data from various sources like drones, satellites, and ground sensors, leaders and soldiers can make well-informed choices and react quickly to evolving situations.

A paradigm change in image processing approaches is being sparked by the merging of machine learning (ML) and artificial intelligence (AI), especially for military applications. Deep learning algorithms have significantly improved our ability to analyze large datasets, identify complex patterns, and make judgments in real time with previously unheard-of precision. In military applications, this convergence of AI and ML offers numerous benefits as follows.

Automatic Target Recognition (ATR): AI-powered systems with machine learning (ML) algorithms may recognize and categorize targets on their own, relieving human analysts of some of the work and possibly speeding up reaction times. Through quick target recognition in congested settings, ATR systems improve operational effectiveness and allow military assets to move more nimbly.

Activities including targeting, monitoring, and command and control must quickly make sense of vast amounts of disparate and sometimes erroneous data. This will undoubtedly call for the use of sophisticated Artificial Intelligence (AI) techniques, particularly those related to visual interpretation. An autonomous system may then take over and try to choose a suitable target from the collection of images and launch a suitable response.

We can summary military applications as Remote Sensing (Remote Sensing Technology, Understanding Images), Image understanding problems (Preprocessing system, Primitive descriptions, Symbolic descriptions, Semantic interpretations, Output descriptions), Computational Vision, The Autonomous Vehicle and many others. More deeply about the topic see in (Du - Ives - VAN Nevel, 2010).

2 WEAPON DETECTION

Automatic Weapon Detection after preprocessing, the images/video sequences can be displayed for operator-assisted weapon detection or fed into a weapon detection module for automated weapon detection. Toward this aim, several steps are required, including object extraction, shape description, and weapon recognition. Unlike other methods, our weapon detection technology relies on research that takes into account not just the visuals of firearms, but also the person's body position. Our findings indicate that this method enables the identification of weapons in low-quality pictures taken by typical security cameras, especially when the weapon is small or in low light, with body pose being particularly beneficial in these situations. The number of false positives can be minimized to almost zero by ensuring that only significant detections, such as a handgun being held by a person in the image, will active an alarm. Approach in detection of weapons and guns:

a) The human pose estimation model will analyze the input frame and predict the pose of every individual in the scenario. Individual are determined using the calculated coordinates, and the best size for each hand area is found using a new factor called the Adaptive pose factor.
b) Every hand area is taken out and utilized to create a fresh unified image.
c) The weapon detection model examines the newly created image and identifies the areas of danger, hands and weapons.
d) The hands that are confidently recognized as weapons.

Mathematical methods for detection of weapon, see Fig. 1., are based on mathematical modelling, as detection of objects, detection of sharp and edges of objects, segmentation of object segmentation of the human pose model. Applications image segmentation techniques in this way is very important, because there is a possibility of recognition potential enemy and potential danger enemy with guns or weapons. Mathematical methods, which are standardly used in this process are segmentation methods (graph cuts, grab cuts, region growing, deep learning, neural networks, machine learning, threshold, level sets methods and many others....).

There are challenges in detection of weapons: The users and clients raise several difficulties. Previous studies struggle to locate reliable data for model training, but this challenge is decreasing in importance due to the sharing of other research and databases. When it comes to surveillance footage, the key features that have a significant impact on the images are the low quality of lighting and resolution, which are typically, addressed using pre-processing methods in many studies. The challenging aspect of identifying weapons in surveillance images is the presence of small-sized weapons that are partially hidden; see (Santos – Héder – Cunha, 2024).

Figure 1 Detection of a gun
Source: https://projectdisarm.com/weapon-detection/

3 SEGMENTATION OF AN IMAGE DATA

In the field of digital image processing and computer vision, image segmentation involves dividing a digital image into various segments, referred to as image regions or objects comprised of pixels. The objective of segmentation is to simplify or alter how an image is represented so it becomes more meaningful and easier to analyze. Image segmentation is commonly employed to identify objects and boundaries within images, such as lines and curves. More specifically, image segmentation involves labeling each pixel in an image based on shared characteristics among pixels with the same label.

Segmentation refers to the general methods that involve dividing an analyzing an image and pulling out pertinent data about certain parts of the picture, like lines, areas and items, as well as how they are connected, see (Felzenszwal-Huttenlochter, 2004, Ford-Fulkerson, 1962, Grady, 2006, Khalifa-Badr 2023). It is essentially a procedure for information. Segmenting an image into subsets based on pixel classification, thereby enabling compression. Assigning specific pixels is for specific categories. Several methods employed for segmentation includes grouping, categorizing patterns and determining grey level thresholds to their similarities and differences with respect to specific features. To the value(s) of specific image characteristics that are quantifiable or assessable individually important group of pixels, see (Yu-Wang-Fu-Kou-Huang-Yang-bang-Gao, 2023, Zhang-Wang 2012).

3.1 SAR DATA

SAR is a type of active data collection where a sensor produces its own energy and then records the amount of that energy reflected after interacting with the Earth. SAR technology provides terrain structural information to geologists for mineral exploration, oil spill boundaries on water to environmentalists, sea state and ice hazard maps to navigators, and reconnaissance and targeting information to military and intelligence operations.

Resolution of ERS SAR is the following: The ERS SAR has a bandwidth of 15.6 MHz, an antenna length of 10 m and a look angle of 23˚, see Fig. 2., Fig. 3.

The ground range resolution is about 25 m and the maximum azimuth resolution is 5 m. The main disadvantage of the SAR and satellite images is that the data extracted from these sensors are not always available for a specific region since they are orbiting and recording data at different frequencies.

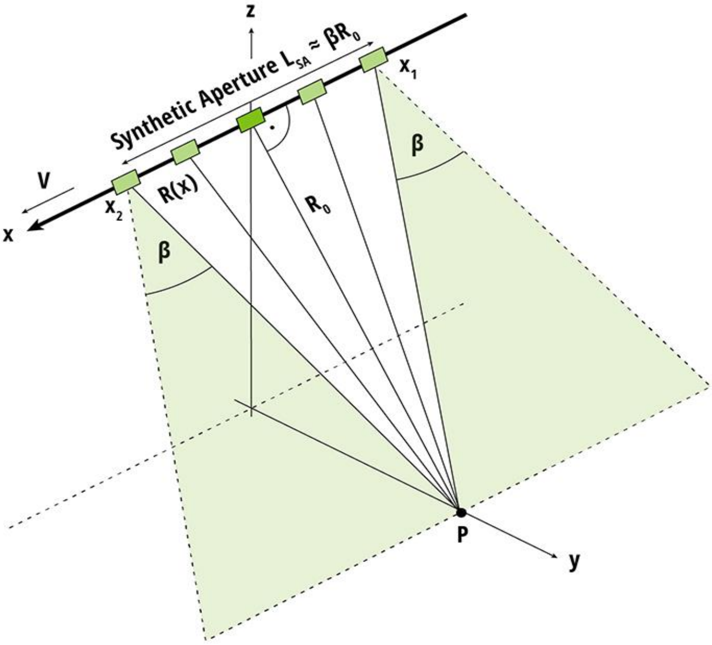

Figure 2 SAR satelite data, Geometry of observations used to form the synthetic aperture for target P at along-track position x = 0. Credit: NASA SAR Handbook.
Source: *https://www.earthdata.nasa.gov/learn/backgrounders/what-is-sar*

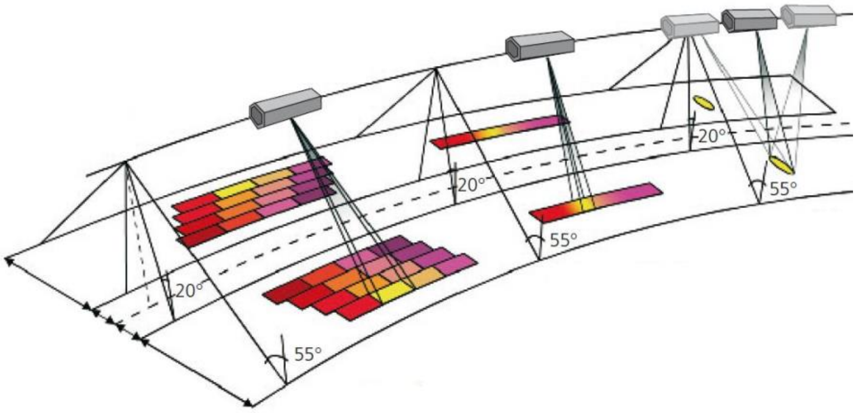

Figure 3 Signals from radar to the earth, From left to right: scan, strip, and spot imaging modes. Image credit: Deutches Zentrum für Luft- und Raumfahrt
Source: *https://up42.com/blog/sar-data-synthetic-aperture-radar-explained*

3.2 SEGMENTATION OF SAR DATA: RESULTS

In this subsection we present our own results given by our software, (Ždímalová-Boratková 2023, Ždímalová-Ghosh-Lasker-Obaidullah-Poornima-Shvydka-Boratková-Kopáni 2023) and (online: Randomwalker, Randomwalker1, Randomwalker2, Randomwalker4, EM509StochasticProcessProject, RandomwalkerSegmentationPython). We implemented mathematics method called random walker and Graph cut and created own software for image segmentation. We focuse on the segmnetation of SAR data, which present landscape areas, specially rivers, see Fig. 4., Fig.5, Fig.6, and Fig.7. It is important to make good segmentation of natural object like rivers, for better understanding of images. Then soldiers can decide how terrain is available for military operations. Source data come from Free databases (Opne Gallery and Open Free Database).

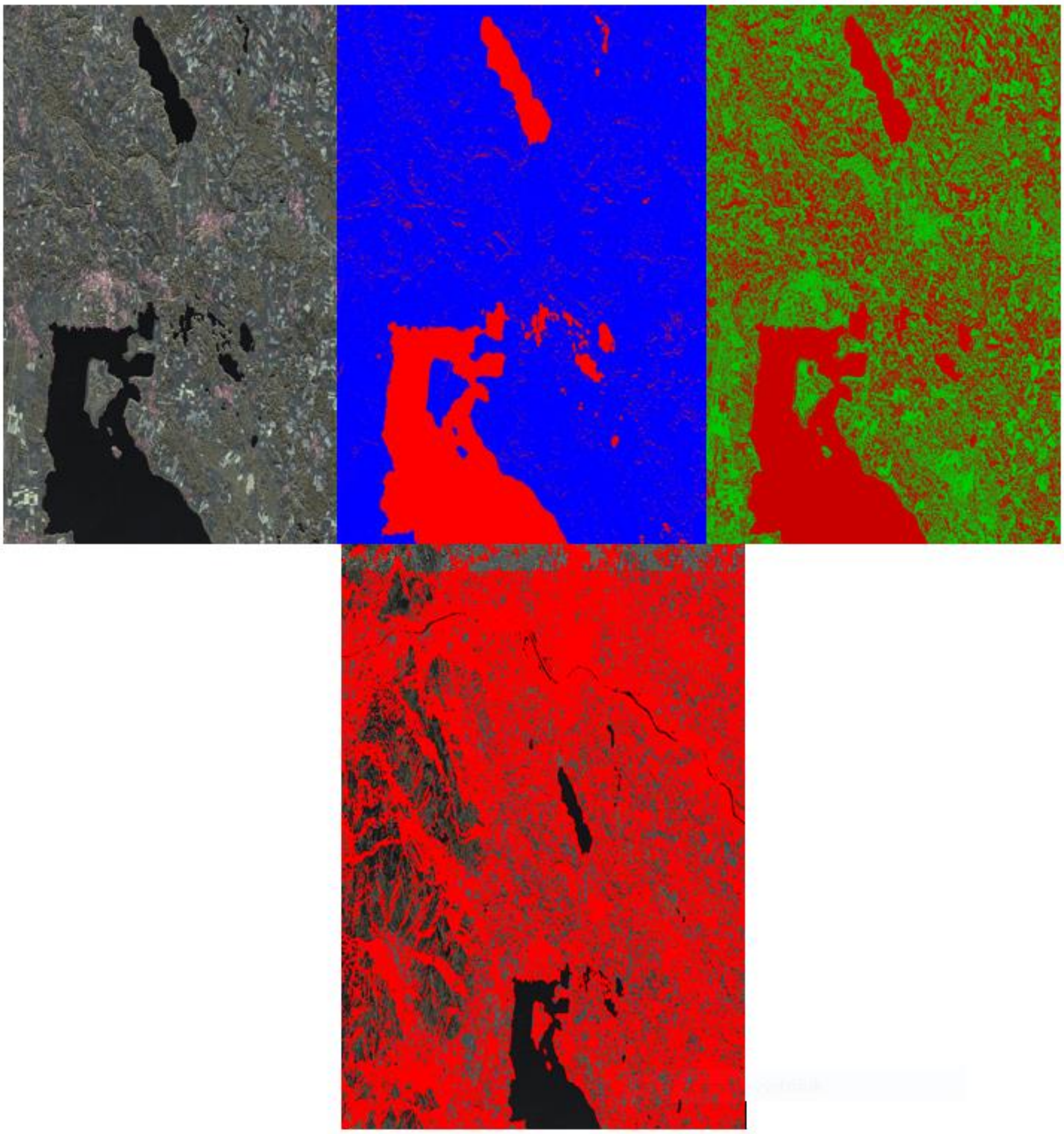

Figure 4 Original SAR data Rossenhein valley, segmented data by Random Walker and Graph cut

Source: Original data: Open Gallery and Open free Database: https://www.capellaspace.com/capellas-advanced-sar-imagery-products/

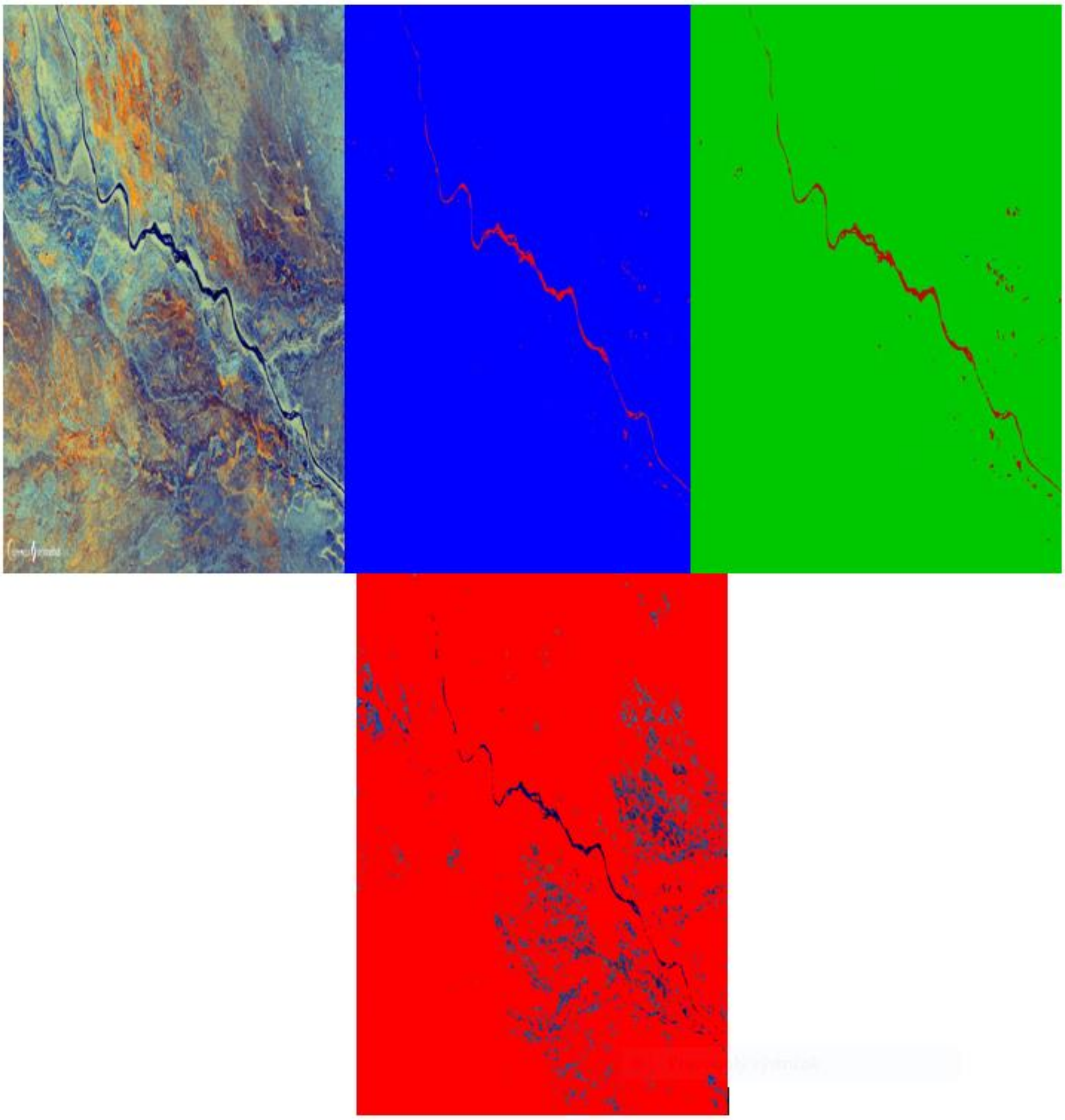

Figure 5 Original SAR data Mitchel River Austria, and segmented data with Random Walker and Graph cut

Source: Original data: Open Gallery and Open free Database: https://www.capellaspace.com/capellas-advanced-sar-imagery-products/

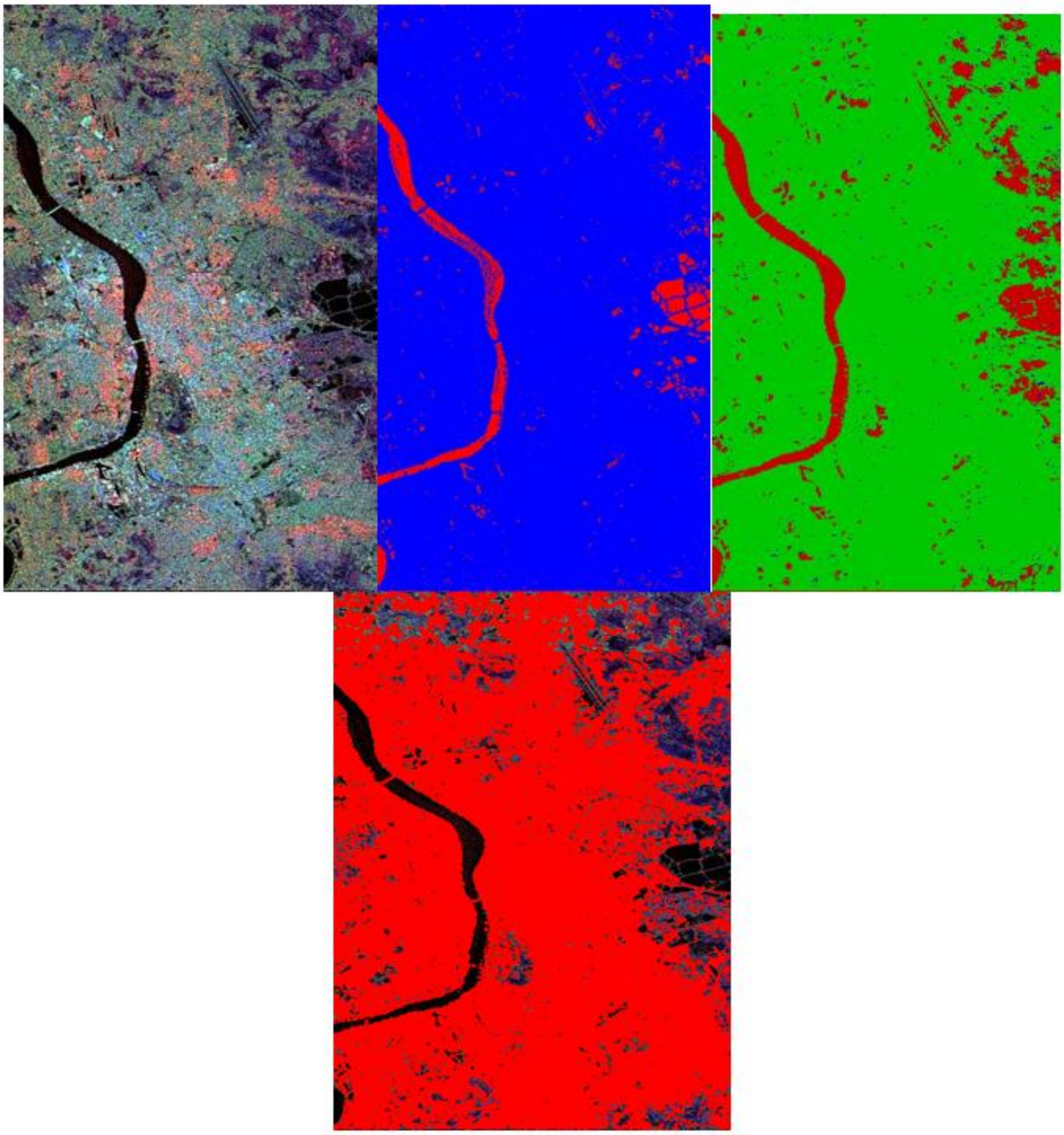

Figure 6 Original SAR data Mitchel River, Austria, and segmented data with Random Walker and Graph cut

Source: Open Gallery and Open free Database: https://www.capellaspace.com/capellas-advanced-sar-imagery-products/

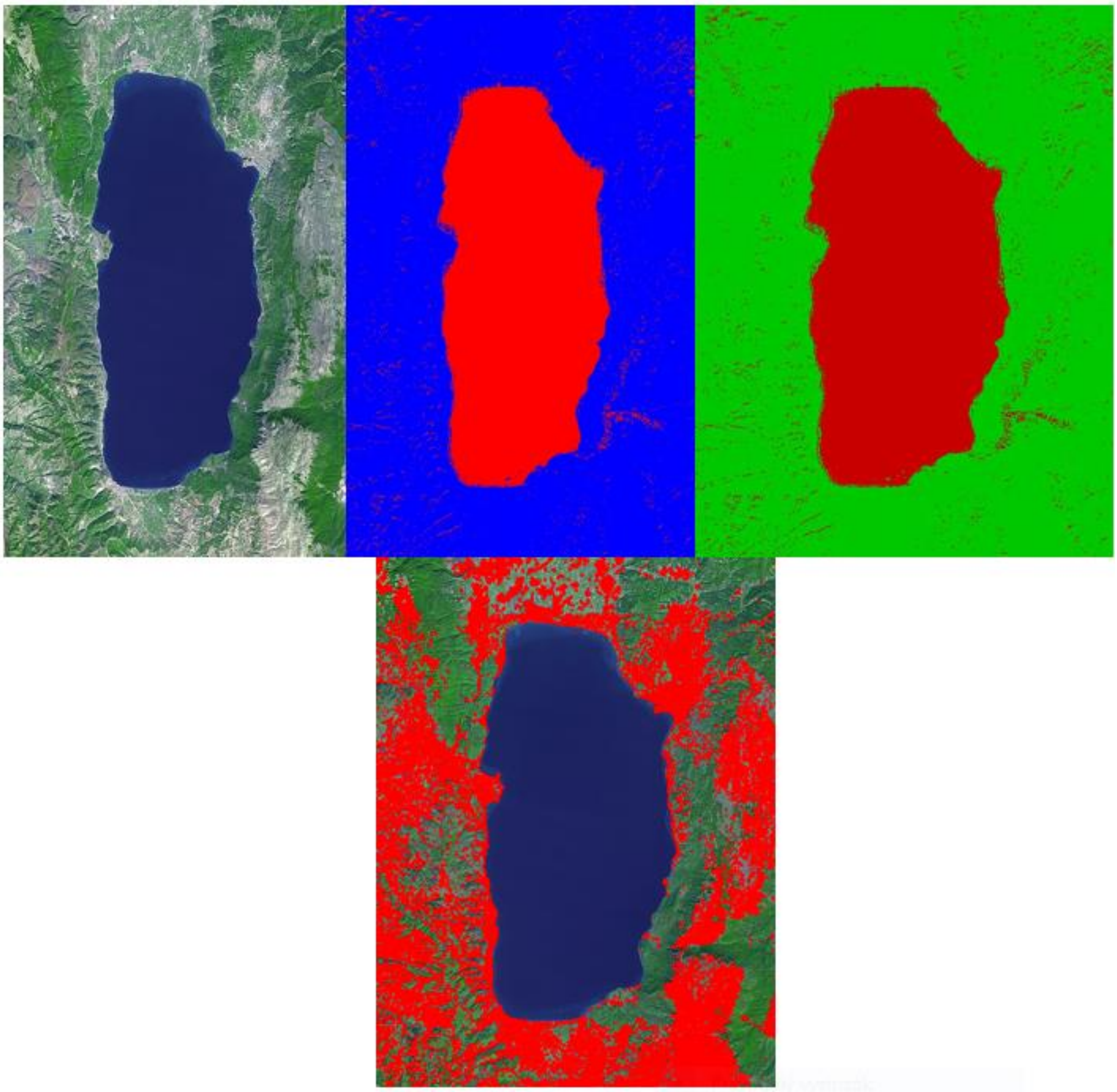

Figure 7 Original SAR data Ohroid lake, Macedonia, and segmented data with Random Walker and Graph cut
Source: Original data: Open Gallery and Open free Database: https://www.capellaspace.com/capellas-advanced-sar-imagery-products/

Radar data

In this part we show segmentation of Radar Data, the Goldstone radar, see Fig. 8.

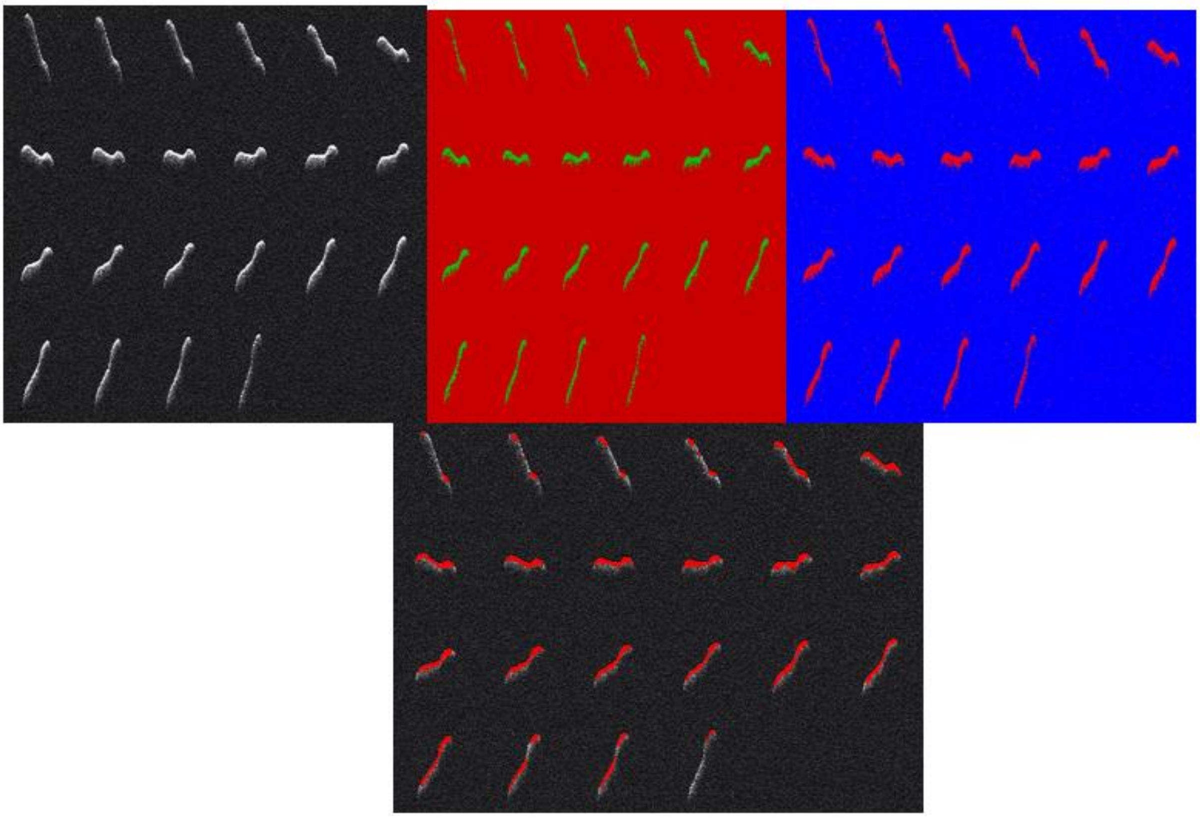

Figure 8 Original Radar data: Goldstone Radar, and segmented data with Random Walker and Graph cut
Source: Original data: Open Gallery and Open free Database:
https://www.capellaspace.com/capellas-advanced-sar-imagery-products/

Next figures show tracking of ships on the sea for security and defense purpose on SAR data, see Fig.9., Fig. 10. Soldiers can watch ships movements on the sea. This kind of tracking object is important in connection with international security and defense of the countries. The army can watch their own ships or detect enemies.

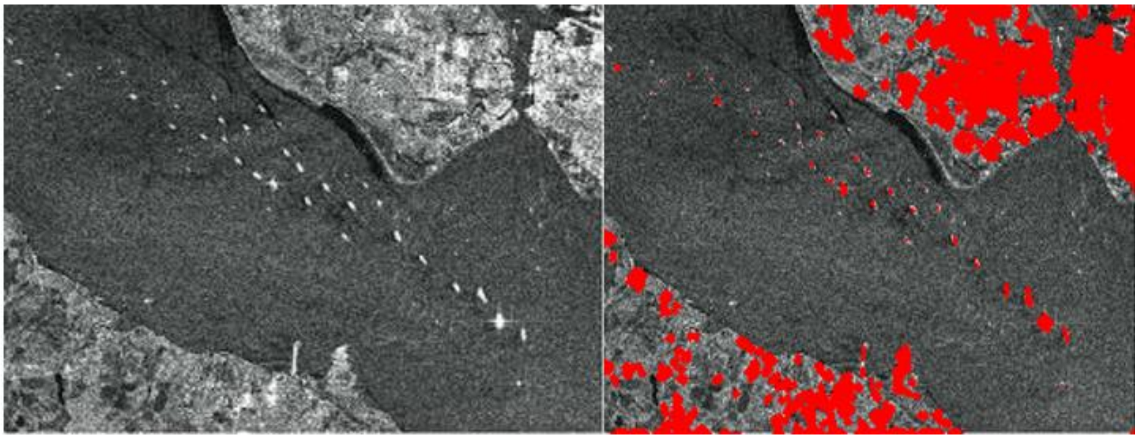

Figure 9 Original Radar data: and segmented data with Random Walker and Graph cut
Source: Original data: Open Gallery and Open free Database:
https://www.capellaspace.com/capellas-advanced-sar-imagery-products/

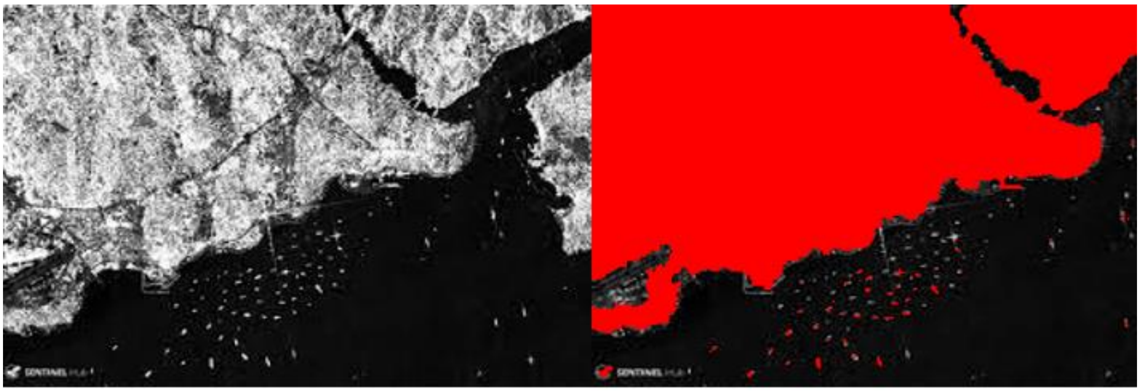

Figure 10 Original Radar data: and segmented data with Random
Walker and Graph cut
Source: Original data: Open Gallery and Open free Database:
https://www.capellaspace.com/capellas-advanced-sar-imagery-products/

3.3. SEGMENTATION OF CRACS IN SIDEWALK, MATERIALS AND BUILDING FOR SECURITY IN MILITARY

Another type of security analysis is for detecting cracks on sidewalks, see Fig 11 and Fig 12. This kind research and analysis is important because of safety transport heavy military weapons on roads, heavy transport military cars and other vehicles on roads, see (Majchút-Brezina, 2023). It is necessary to prepare and predict the safety of the roads, sidewalks and the terrain. In this connection we consider even segmentation of cracks and cracks analyses oft technical analyses and cracks of buildings.

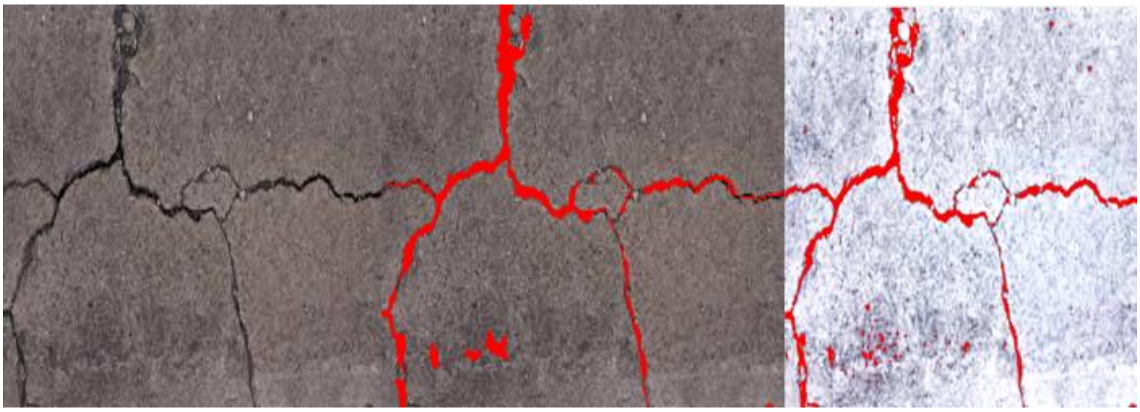

Figure 11 Original digital data: and segmented data with Random
Walker and Graph cut
Source: Original data:
https://commons.wikimedia.org/w/index.php?search=cracks+in+material&title=Special:MediaSearch&go=Go&type=image

Figure 12 Original digital data: and segmented data with Random Walker and Graph cut
Source: Original data:
https://commons.wikimedia.org/w/index.php?search=cracks+in+material&title=Special:MediaSearch&go=Go&type=image

Analysis of cracks and sidewalks as well buildings and materials provide information about possibility of damage of materials, roads and also the sickness and no stability of building structures.

CONCLUSION

As summary, we can tell that image processing and computer vision plays an important role in the defense and military area. In this contribution, we deal with the image processing of SAR data and digital image data with cracks. We focused on the segmentation of SAR data and its processing for better visualization and for better visual analyzing of data. The aim was to show the area in SAR data, the tracking of ships on the sea and detection of cracks in sidewalks for security and defense military purposes. We implemented and did optimization of two methods, Random Walker algorithm and Graph Cut algorithm. We used C++ and Python language for implementation with our own created computers program we segmented SAR data. We provided good segmentation for dividing optical data into object and background regions.

Open questions: There still come new techniques as Al Techniques, Neural Network and Machine learning techniques. These can improve segmentation process, reduce noise on the images, improve communication between civil and military staff, improve collection of big data and creating extremely large datasets.

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