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Mathematical Modelling of Segmentation Synthetic Aperture Radar Data for Military Purposes

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Abstract

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. In this contribution we discuss and use mathematical modelling for segmentation of image data. We focus on Synthetic Aperture Radar (SAR) data, which plays an important role in military area. Our own approach brings our own software for segmentation of SAR images. We use discrete mathematical models, graph cut, grab cut and random walker. Our own approach is in implementation of these algorithms and their implementation in programming languages as C, C++, and Python. We provide segmentation of noise images, and we focus on segmentation of paths, roads, objects, rivers etc. We provide segmentation of SAR images. We do preprocess and post processing of data based on requirements of authors. The advantage of our methods is in the better and clearer segmentations with better boundaries. Our solution can also proceed noise data, what is the big problem by SAR data analyses. We deal with SAR data, and we try to segment objects. There are some limitations for processing real image data. We cannot deal with data which has too many lines, or too big distances in shadow colors. Another limitation brings scaling of images and too big and too noisy data.

KEY WORDS: *Image Processing, SAR segmentation, Graph Cut, Grab Cut, Random Walker*

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1. Introduction

Digital image processing is a field of computer science and engineering that focuses on using algorithms and mathematical models to analyze, manipulate, and enhance digital images. The primary goal of digital image processing is to improve the visual quality of images and to extract meaningful information, enabling automation in various image-based tasks. As imaging technology becomes increasingly sophisticated, digital image processing has become crucial in numerous sectors, including defense, healthcare, industry, and environmental monitoring. In this context, the application of image processing extends far beyond basic image enhancement, encompassing a comprehensive range of steps that serve to optimize the interpretation and utility of digital data. The typical steps of digital image processing include:

1. **Image Acquisition.** The initial step involves capturing an image through sensors, such as cameras, satellites, or other imaging devices, which convert physical phenomena into a digital form.
2. **Image Enhancement**. This phase aims to improve image quality by refining visual elements such as contrast, sharpness, and brightness to make important features more distinguishable.
3. **Image Restoration**. The process of restoring a degraded image, often due to noise, motion blur, or other distortions, to recover its original form or enhance its quality.
4. **Color Image Processing**. Techniques applied to manipulate and analyze images in the color space, helping with tasks such as object recognition and classification.
5. **Wavelets and Multiresolution Processing**. This method involves breaking down an image into different scales or resolutions to analyze features at varying levels of detail.
6. **Image Compression**. A process to reduce the storage size of an image without significant loss of quality, critical for efficient storage and transmission.

7. **Morphological Processing**. A technique focused on the structure and shape of objects within an image, often used for object detection and segmentation.
8. **Image Segmentation**. The partitioning of an image into distinct regions or objects for further analysis, critical for applications such as object tracking and recognition.

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's important to know what's new in computer vision and how it can be used in the defense business. The role of image and video processing in army and military stuff: Helicopters and other military vehicles use vision systems enabled by rugged embedded hardware to operate in degraded visual environments. Currently, the military and technology industry collaborate to provide frontline warfighters with the latest intelligence. Electro-optics, along with advanced embedded computing image and video processors, collaborate to condense the overwhelming amount of information into useful intelligence due to the rapid processing speed of modern systems. However, we condemn with moral outrage and disapproval individuals who are deceived and corrupted by the temporary allure of pleasure, so consumed by desire that they cannot anticipate the inevitable suffering and difficulties that will follow; and the same amount of fault lies with those who neglect their responsibilities due to their lack of strength.

This can also be expressed as avoiding hard work and suffering. Identifying autonomous targets in drones and missiles is straightforward, as is using satellites to identify hostile targets on land, in the air, or at sea. Combat pilots benefit from integrated head-up displays for targeting and situational awareness, while infantry use head-mounted vision systems for situational awareness. All these limitations belong for the general processing of digital images, of Sar data and other visual objects. They can be considered as general problems and limitations by the processing of digital image processing.

In the field of aerospace, vision-based navigation or star tracking, spectral sensing for mapping Earth and lunar terrain, and AI-based navigation removing satellites from orbit are key technologies. In relation to avionics, examples include the use of vision-based technology in cockpit simulators and the installation of closed-circuit cameras within the aircraft for pilot monitoring. Electro-optical sensors contribute a wealth of information to the situational awareness system. Curtiss-Wright's Garnett explains that improvements in electro-optics enhance the quantity and quality of information accessible, while high performance embedded computing can handle the vast amount of real-time data and deliver it in a user-friendly format using modern rugged displays. The potential of both computation and software lies in their ability to process data in new ways to reduce operator task overload, while also introducing novel ways of analysis and presentation in real-time, for optimal mission results. If you're unable to quantify or spot the danger, you won't be able to control or react to it. Instantaneous image analysis is essential for automated target identification, tracking of friendly and enemy forces, reducing instances of friendly fire, accelerating the OODA loop, among other things. We mention some applications of computer vision and image processing in the security sector. We present some examples of computer vision contributing to enhancing the precision and overall efficiency of defense equipment: [1, 5, 8, 9].

Official studies show that facial recognition technology is increasingly being used in different sectors, such as defense, to improve security and identification processes. Computer vision allows for the use of face recognition, an essential element in defense that boosts security and streamlines precise identification. This technology offers a more efficient and streamlined method for reaching these goals. Face recognition systems make it easier to identify people by utilizing computer vision technology. They study facial characteristics like the eyes, nose, and mouth to generate an individualized facial blueprint. This pattern is then matched with a database of familiar faces, allowing military personnel to easily find individuals that could be dangerous. By utilizing computer vision and facial recognition technology, defense forces can improve security measures, speed up identification procedures, and quickly react to possible risks or dangers. This technology enables them to effectively protect the well-being of people and uphold a safe atmosphere. Facial recognition technology can be utilized in defense facilities and for counter-terrorism purposes.

Research has revealed an increase in the use of object recognition technologies in a range of industries, including defense. The Defense Advanced Research Projects Agency has also been actively dedicating resources to the research and development of object recognition. This technology depends on the visual characteristics of objects to accurately identify them. They assist the military in evaluating potential threats, monitoring resources, and enhancing the security of defense locations through threat assessment, inventory management, and safety improvement.

Surveillance and monitoring, which are made possible by computer vision, are very important for defense because they can detect intrusions, surveil borders, and secure defense sites. It emphasizes the increasing adoption and investment in surveillance technologies to safeguard military installations, border areas, and critical infrastructure. Computer vision programs installed on military bases can assess the constant feed of visual data immediately to instantly.

In a study by the Federation of American Scientists [8], self-driving vehicles with computer vision successfully navigated challenging terrains and conducted logistics tasks with less human oversight. These vehicles displayed increased operational efficiency, decreased risks to personnel, and improved mission success rates. In this regard, we can discuss enhanced maneuverability and increased realism. Incorporating computer vision technology enhances the precision and dependability of self-driving vehicles during critical scenarios. These vehicles are capable of carrying out significant duties with minimal manual intervention or input. This reduces the potential danger to military personnel and makes operations more efficient.

A study published in the Journal of DTIC [8] revealed that using AR technology in military training can improve soldier performance. This improvement is attributed to the ability of AR to provide real-time information, enhance decision-making, and simulate realistic combat situations. According to a report by Zion Market Research, the global augmented reality in the defense market is expected to reach a value of $128 Billion by 2028, growing at a CAGR of around 29% from 2021 to 2028. This showcases the increasing adoption of AR technology in defense training applications. This can be applied in improvement of training and defense resource optimization through computer vision and augmented reality.

Research has demonstrated that the user-friendly design of the pilot's interface in the cockpit, along with their engagement with the image control on the display, decreases the burden on the pilot and boosts their reaction speeds, thereby augmenting the success of the mission. The use of computer vision technology aids in understanding human movements, leading to a smoother and more natural interaction between people and machines in the defense industry. This improves teamwork in the intricate setting of defense activities.

Biometric recognition, underpinned by computer vision technology, plays a pivotal role in upholding security standards. It ensures that access to sensitive domains within the defense sector is exclusively granted to individuals devoid of any criminal affiliations, thereby maintaining the integrity of security operations. Defense systems can use biometric recognition to ensure only authorized personnel have access to restricted areas or classified information. This ensures the safety of sensitive information and assets. These include protected access and efficient security operations.

Studies in medical and scientific publications have demonstrated that technology designed for visual recognition can reliably identify severe injuries, including gunshot wounds, broken bones, and bleeding inside the body, achieving a success rate higher than 90%. This enhanced accuracy enables faster evaluations and targeted medical interventions, which can be crucial in life-threatening scenarios. The expansion of medical applications is driven by the increasing demand for advanced medical devices that can enhance the success and speed of medical support in war zones. Prompt treatment and remote medical support are key elements in delivering healthcare.

Certain government agencies and armed forces have incorporated computer vision algorithms into their analysis of satellite imagery. This app allows for the recognition and monitoring of important items, surveillance of border actions, and identification of security risks, thus boosting the strategic scope of defense maneuvers. We highlight the increased precision of immediate data and quicker identification of patterns.

In the defense sector, it is essential to conduct thorough damage assessment to determine the effects of attacks, natural disasters, or accidents on vital infrastructure. Computer vision has a significant impact in this process as it utilizes advanced algorithms and image analysis techniques to evaluate structural damage and pinpoint possible vulnerabilities. Below are the main components of applying computer vision for damage evaluation in the military field. This is related to improved visual inspection, identifying vulnerabilities with computer vision, quick response, and decision-making, monitoring the environment, and detecting hazards. One-way computer vision can be applied is detecting and tracking wildfires, monitoring terrain or vegetation changes, and identifying hazardous materials or chemical leaks. Through constant analysis of visual data, military, and defense personnel can identify potential environmental dangers in advance and implement necessary actions to minimize their effects.

Computer vision utilization in the defense industry has the capability to cause significant disruption and enhance the effectiveness of current systems. Computer vision can enhance processes by increasing efficiency, accuracy, and optimization, making it simpler to surveil the enemy, pinpoint targets, and detect hostiles. The main point is that computer vision provides the military with advanced tools to update their performance, including better surveillance, increased lethality, and enhanced military operations. With the use of computer vision, the military can obtain important information and data securely, as well as make informed decisions and act quickly to safeguard national security. Due to constant technological advancements, keeping up with the latest in computer vision is crucial for leveraging its applications in the defense industry.

In our contribution we focus on the image processing of the digital images concretely SAR images and SAR data. In our research we study and provide segmentation process of SAR data. We present special methods, graph cut method and random walker method. We provide our own implementation in the programming language C++ and Python. With these software applications we segment SAR data and provide image analyses. The strong point of our approach is that our method can process as well blurry data as well as data with noise. At the end we bring the results obtained by grab cut algorithm, where we can get the whole segmented object. Our methods bring in general better segmentation results in the sense of better edges boundaries. Both techniques can work and proceed the natural noise on image data.

2. Synthetic Aperture Radar Data

Synthetic Aperture Radar (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˚. 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.

Differences between multi-looking processing produces enhanced radiometric resolution is in higher sensitivity to brightness changes and less noise. The single look image on the left has significant speckle noise but the multi -look version on the right had much improved image clarity and target detectability. Synthetic Aperture Radar (SAR) represents a type of active remote sensing technology that uses microwave electromagnetic radiation to produce and send data to the surface of a target location. SAR imaging is frequently used in national security applications since it is unaffected by weather, geographical location, or time. In this system, many approaches are examined, to improve automation for segmentation and classification. The utilization of Deep Neural Networks (DNNs) to classify SAR images has gotten a lot of attention, and it usually requires several layers of deep models for feature learning. With insufficient training data, however, the DNN will get affected by the overfitting issue. The major purpose of this work is to make a development on introducing a new framework for SAR image segmentation and categorization using deep learning. Owing to the coherent nature of the backscattering signal, SARs create speckle noise in their images. If the image has noisy material, classification becomes more challenging. Hence, the pre-processing of the images is employed by linear spatial filtering to remove the noise. [15]

3. Image segmentation

It is the process of dividing an image into multiple segments or regions, where each segment represents a homogeneous part of the image with similar characteristics. The goal of image segmentation is to simplify or reduce the representation of an image and allow easier analysis or processing of the image at the segment level. Also, for example, in medicine, image processing by computational algorithms is used because of to automate the process of analyzing larger amounts of data. Image segmentation can be performed in a variety of ways, including methods based on color, intensity, texture, edges, and other image properties. It is often used in various fields such as image processing, computer vision, medical diagnosis, robotics, and many others. Segmentation allows different parts of an image to be analyzed and identified.

1. **Medical images**: In medical diagnostics, image segmentation is used for dentification and localization structures in medical images such as CT scans, MRIs or X-rays. It helps in diagnosing diseases and planning surgical procedures.
2. **Automotive**: In the development of autonomous vehicles, image segmentation is critical for identifying objects around the vehicle. This technique enables the vehicle to recognize roads, vehicles, pedestrians, and other objects on the road.
3. **Safety systems**: In surveillance and monitoring systems, image segmentation is used to identify and track the movement of people or objects based on their shape and movement.
4. **Computer vision and object recognition:** Image segmentation is used in the field of computer vision to recognize objects and their boundaries in real time. This is important for a variety of applications, including interacting with devices using cameras.
5. **Industry**: In industrial applications, image segmentation is used for quality control products, monitor processes and identify irregularities or defects.
6. **Agriculture**: In agriculture, image segmentation can be used to identify crops, plant growth monitoring or disease detection. [8]

In this contribution we focus mainly on SAR data.

4. The Mathematical Background

For image segmentation there are several mathematical algorithms and methods. They come from different parts of mathematics and include also different kinds of mathematical tools, even their combinations. We can mention classical methods (threshold methods), gradient methods (region growing methods), clustering methods, graph methods (graph cuts, grab cut methods, intelligent scissors), mixed methods with combination of probability (random walker), mixed methods with mixed Gaussian models. At least but not last, we mention neural networks, machine learning methods, deep learning methods, aggregation methods, fuzzy methods and others [1, 2, 3, 4, 8].
We explain in detail just three algorithms, which bring our own implementations and own new software for processing of image data.

4.1. Random walker algorithm and segmentation via Random walker

The term random walk, translated as random walk, was first published by mathematician Karl Pearson in 1905, [6]. The definition of this term is about assumptions and probabilities. Assume that at each step the user starts from some base point. He moves a fixed length with a randomly chosen angle. What is the distribution of the walker, over multiple steps? This is exactly the random walk problem. In the same year Albert Einstein published his paper, he modeled Brownian motion as a random walk. This paper had a huge impact on the whole algorithm, because it started to provide proofs of discrete particles in time. So, most scientists began to believe that the matter had a continuum character. And this is something continuous, e.g. in mathematics it can be a set of real numbers (so also a number axis), or any interval of that set. Image segmentation using random walk was first applied in 1979, where random walk was first used in computer science for texture discrimination, and more researchers started to pay attention to this. The Random Walker algorithm received attention only later, as it was first published by Grady in 2006 under the name Random Walker. Algorithm definition: A random walker is a walker moving on an edge between vertices with a probability that is proportional to the capacity on the edge. A weighted graph $G(V, E, W)$ is constructed to represent the relationships between nodes, where V is the set of vertices, E is the set of edges, and W is the weights added to each edge to denote the similarities between them. The goal of clustering is to divide the data nodes into several groups, so that nodes in the same group are similar and those in different groups are dissimilar. The solution to the clustering problem occurs here in finding the region of a given graph. Moreover, in addition, edges within the same group have high weight and in different groups have low weight in turn. It ensures that the points are distinct from each other and within the same, cluster are like each other. When segmenting an image or data, the output of the algorithm will be the segmentation of K objects that correspond to K groups of source pixels and have different labels. The algorithm will label the most likely label to assign to the non-source pixels. For each such pixel, the probability of a pedestrian starting from that pixel reaching the source pixel labeled s first will be computed. Thus, for each pixel there will be K probabilities [6, 11, 12].

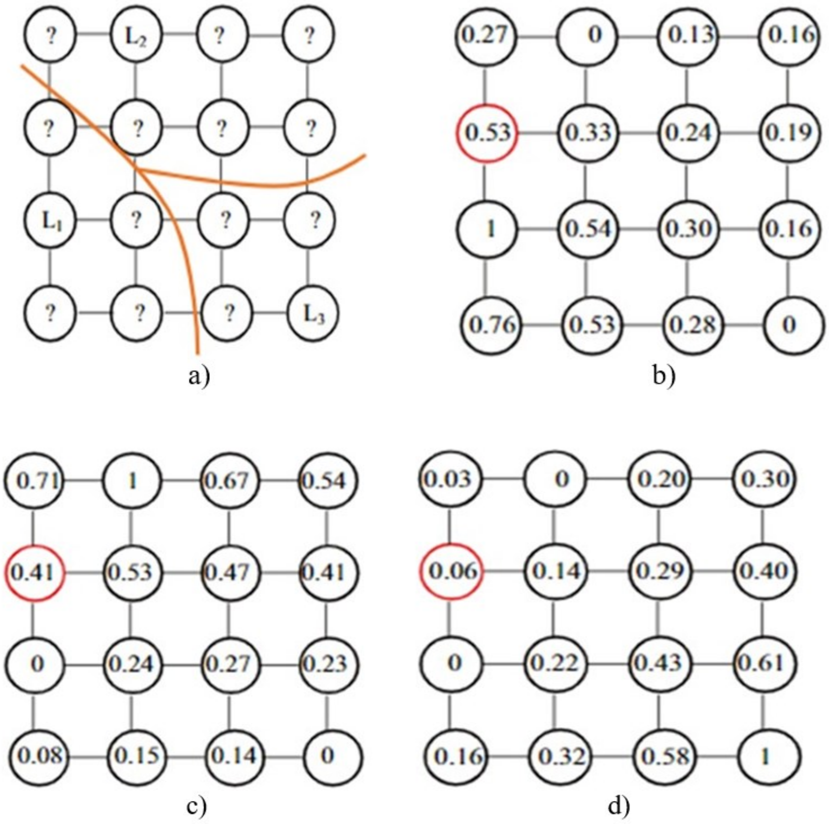


Fig.1. For each pixel there will be K probabilities: a) Beginning of the algorithm; b) The red point from which we calculate what is the probability of the walker getting to points L1; c) The red point from which we calculate what is the probability of the walker getting to points L2; d) The red point from which we calculate what is the probability of the walker getting to points L3.

We can illustrate the random walker model in the figures above. We have a 4x4 graph with three starting points, L1, L2, L3 and a subsequent segmentation. Fig. 1(a) shows these points and in the next figures Fig. 1 (b), (c), (d) we can see the red point from which we calculate what is the probability of the walker getting to points L1, L2 and L3, see Fig. 1. The probabilities are 0.53, 0.41 and 0.06, which gives us a total of exactly 1, i.e., a 100% fraction. Since the highest probability reaches 0.53 at point L1, the marked starting point of our walker belongs to the same cluster as point L1.

The basic algorithm is simple, and we can formulate it equivalently to the combinatorial Dirichlet problem defined on the graph. Given data nodes in a connected graph $G(V, E, W)$ with n vertices $V = \{v1, v2, \ldots, vn\}$ and m edges $E = \{e1, e2, \ldots, en\}$ we can construct a graph. To be able to partition vertices into clusters, the algorithm needs K labeled vertices. From this we can make a so-called combinatorial Laplacian matrix. We will not discuss this in depth, but the basic steps of this algorithm are:

1. Convert pixel intensities to edge weights in the graph.
2. Selecting and labeling K sets of source vertices (pixels).
3. Solving a system of equations, yielding K probabilities for each node.
4. Determine a label for each pixel based on the maximum probability value.

A problem can arise if we select a few source pixels, because the output of the algorithm is a slice that separates the source pixels from the rest of the image [6, 13, 14].

Description of the random walk algorithm

#0. Creating the graph.

#1. Initializing the graph.

An empty graph representing the image is created. Each pixel of the image becomes a vertex. of the graph. Each vertex is given a vxy numbering, where $0 < x \leq$ image width, $0 < y \leq$ image height

#2. Adding edges.

Add edges between vertices that represent adjacent pixels in the image. Per vertex neighbors with coordinates *(x, y)* are vertices: *(x-1, y), (x+1, y), (x, y-1), (x, y+1)*. Each edge is assigned a weight equal to the intensity difference of neighboring pixels in the image. Let us denote it as *wij*, where *i* and *j* are the respective row and column in the graph incidence matrix.

#3. Vertex initialization.

Each vertex is assigned a truth probability *(n, pxy)* for each segment *n, pxy=0*, where *n* and *m* is the visible number of segments. This value will represent the probability that a vertex *v* with coordinates *(x, y)* belongs to segment *n*. Also, each vertex will store information about the intensity of the corresponding pixel $0 \leq$ Ixy ≤ 255th of the associated pixel.

#4. Creating semantic tags.

A semantic tag in the context of the random walk algorithm means the rules according to which the algorithm processes the apparent segments. For example, we need to process the following image. Let the black parts be segment number *1*, the white parts be segment number *2*. The black parts can obviously be defined as those where the intensity satisfies the following condition *Ixy < 20.* The white vertices should satisfy the condition *200 < Ixy*. Thus, we have processed a larger part of the image. We are left with only those pixels that do not satisfy any rules. In other words, the grey pixels, which represent a fuzzy gradient on the segment boundary. Just such fuzzy pixels will be solved using the random walk algorithm.

#5. Random walk.

Movement with respect to the similarity of the Neighbor's properties will be selected with respect to similarity of pixels in the selected property. For example, we take intensity. We will always select the neighbor with the smallest difference in intensity. Thus, we will only move on similar vertices, which will give us a higher probability that the peak we are studying and the peak-marker we encounter will be from the same segment [6, 9, 11, 14].

Random walker. Image segmentation has often been defined as the problem of localizing regions of an image relative to content (e.g., image homogeneity). However, recent image segmentation approaches have provided interactive methods that implicitly define the segmentation problem relative to a particular task of content localization. The random walker algorithm determines the segmentation of an image from a set of markers labeling several phases (2 or more). An anisotropic diffusion equation is solved with tracers initiated at the markers' position. The local diffusivity coefficient is greater if neighboring pixels have similar values, so diffusion is difficult across high gradients. The label of each unknown pixel is attributed to the label of the known marker that has the highest probability to be reached first during this diffusion process. In this example, two phases are clearly visible, but the data are too noisy to perform the segmentation from the histogram only. We determine markers of the two phases from the extreme tails of the histogram of gray values and use the random walker for the segmentation [6, 9, 11, 12, 13, 14].

Random Walks for image segmentation. First random walks are introduced in the order of *1D* (without barriers and with barriers), 2D (without barriers and with barriers). Then Markov property is explained. The Markov property is proved for the *1D* simple case and a complicated *2D* case with both absorbing and reflecting barriers. Image segmentation problem is introduced from an application point of view and converted into a mathematical formulation. Random walker algorithm for image segmentation is introduced and it is proven to be a Markov process. The study is concluded by implementing the Random Walker algorithm and testing it by segmenting a set of images.

Another approach:

Generating a random walker for image segmentation involves defining a graph where each pixel in the image is represented by a node, and the edges between nodes represent the similarity between the corresponding pixels. The random walker algorithm then uses this graph to segment the image by assigning labels to each pixel based on the connectivity of the graph. There are several open-source tools available for implementing the random walker algorithm for image segmentation, including [6, 9, 11, 12, 13, 14]:

1. scikit-image: A Python library for image processing that includes an implementation of the random walker algorithm.
2. ITK-SNAP: A software application for medical image segmentation that includes a random walker algorithm.
3. Fiji: An open-source image processing package that includes a plugin for the random walker algorithm.

To use these tools for simulating real-world scenarios, you would need to provide appropriate input data in the form of images or other types of data that can be processed by the algorithm. You may also need to modify the algorithm parameters to achieve the desired results for your specific application.

We implemented the algorithm and created our own software providing image segmentation. We present original SAR data [15] from open Gallery and provide results of segmentation via Random Walker in the Fig. 2., 3., 4. and 5.

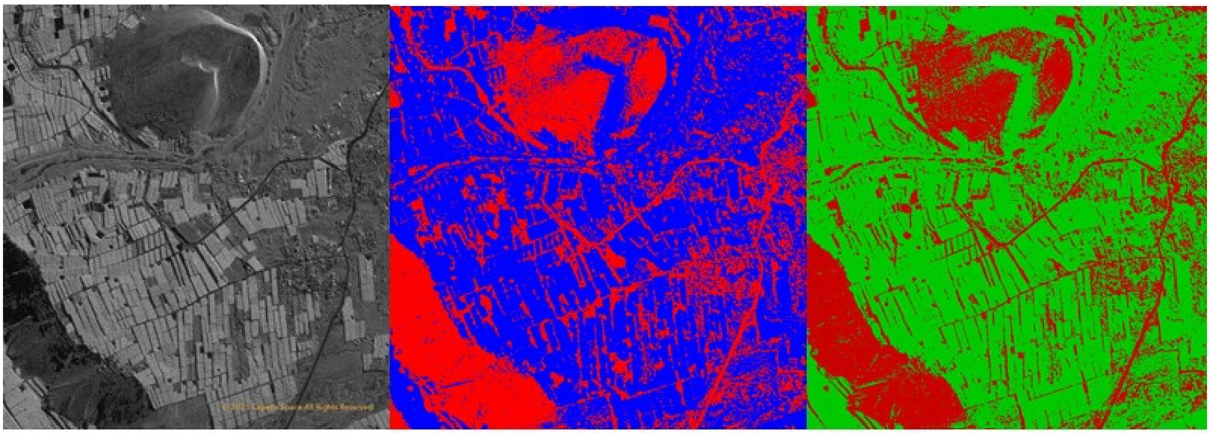
5. Results

In this study, we analyzed Synthetic Aperture Radar (SAR) data obtained from an open-source, freely licensed repository, as referenced in source [15]. Open-source SAR datasets provide a valuable resource for research and experimentation, allowing for the testing and validation of new algorithms without the constraints of proprietary data.

To process and analyze this data, we developed our own custom software, implementing state-of-the-art segmentation algorithms tailored for SAR image processing. The use of in-house software enabled flexibility in optimizing the algorithms for specific tasks, such as object detection and boundary delineation, which are critical for accurate interpretation of SAR imagery. By employing custom-built tools, we were able to fine-tune parameters and enhance the performance of segmentation algorithms like the Random Walker and Graph Cut techniques, ensuring that the SAR data was processed in a manner suited to its unique characteristics, such as speckle noise and resolution variances.

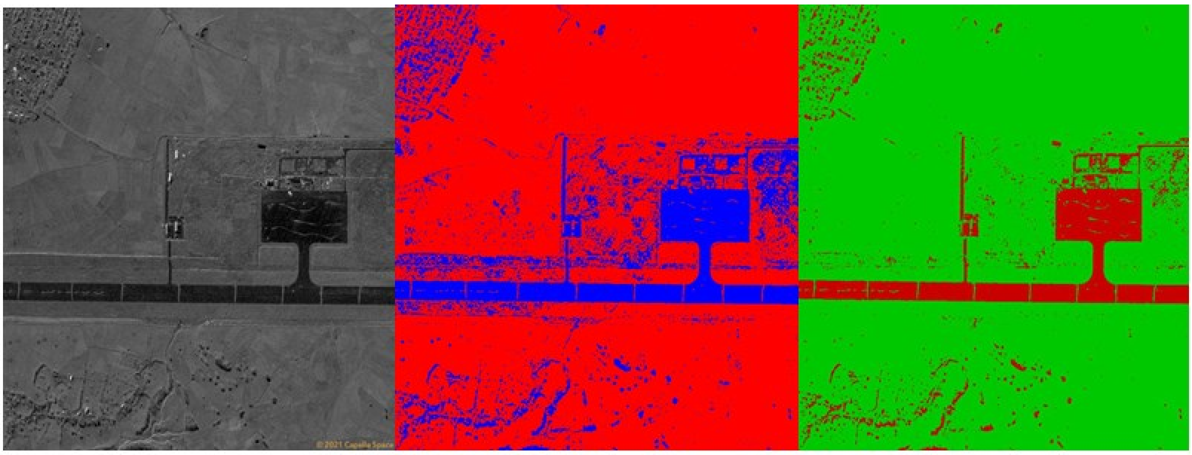
The use of open-source SAR data facilitated the reproducibility of our results, as this data is accessible to the wider scientific community. This allows for further experimentation and comparison across different research groups, contributing to advancements in SAR image analysis. The custom software also provides a platform for future improvements and the integration of additional image processing techniques, enabling continuous development in the field of SAR data analysis for defense and surveillance applications.

5.1. Segmentation via Random walker method [12, 13, 14]



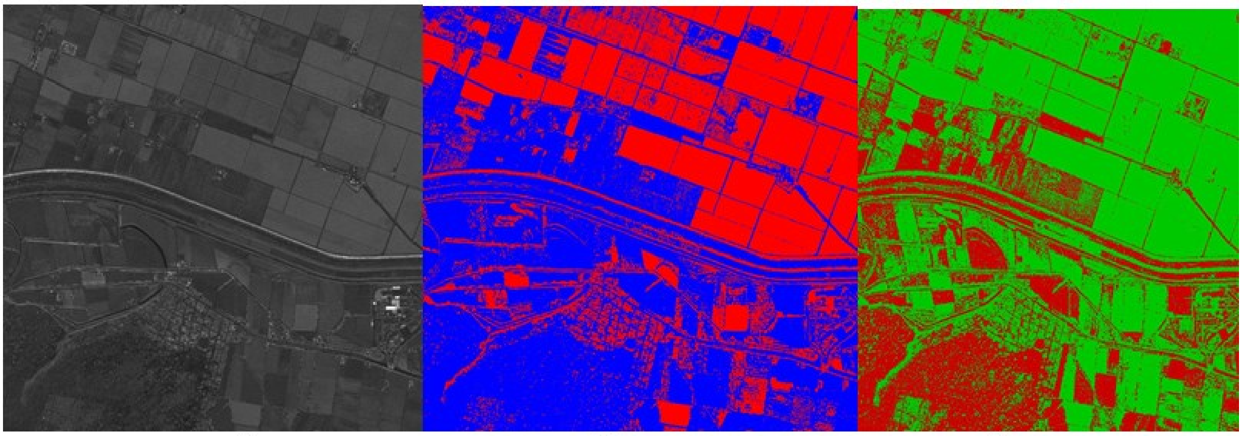
a) b) c)

Fig.2. Data source explanation: a) Original data, source: [15], b) Segmented data, c) Segmented data



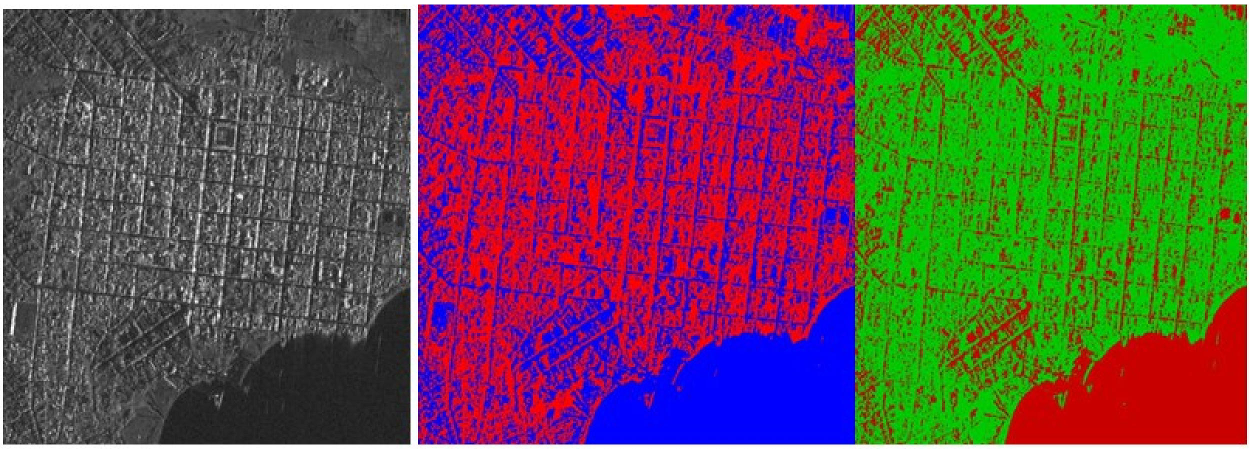
a) b) c)

Fig.3. Data source explanation: a) Original data, source: [15], b) Segmented data, c) Segmented data



a) b) c)

Fig.4. Data source explanation: a) Original data, source: [15, 16], b) Segmented data, c) Segmented data



a) b) c)

Fig.5. Data source explanation: a) Original data, source: [15], b) Segmented data, c) Segmented data

5.2. Segmentation via Graph Cuts method: Segmentation using maximum flow and minimum cut, [1, 2, 3, 5]

a) b)

Fig. 6. a) Original Image: The 3x3 image, we choose the input data, object O and background B. b)Segmented Results

The two algorithms, the Ford-Fulkerson and Edmonds- Karp algorithms, see [1, 2, 3], we can use one of them to find the maximum flow and the minimum cut, see Fig. 6. We will now show how a simple 2D segmentation works on a 3x3 image, based on the figures and a brief description, see Fig.6, Fig.7, and Fig. 8.

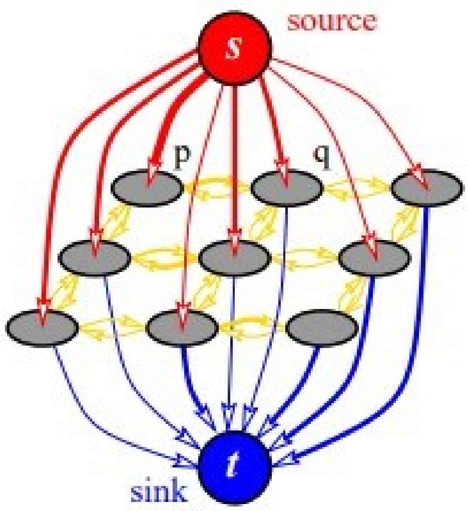


Fig. 7. Oriented Network

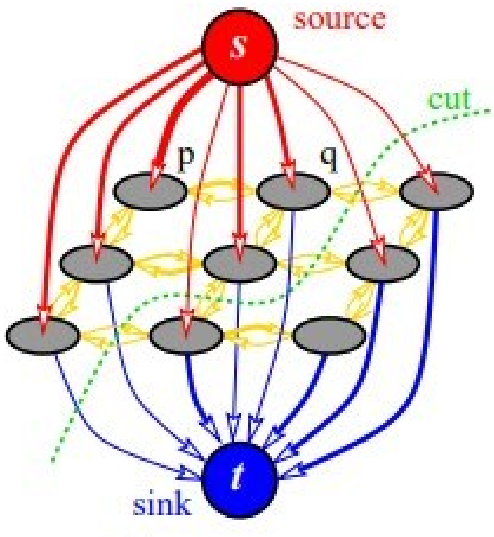


Fig. 8. Minimal Cut

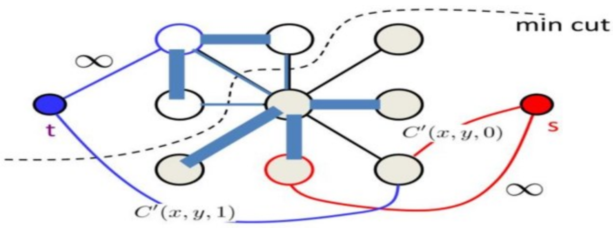
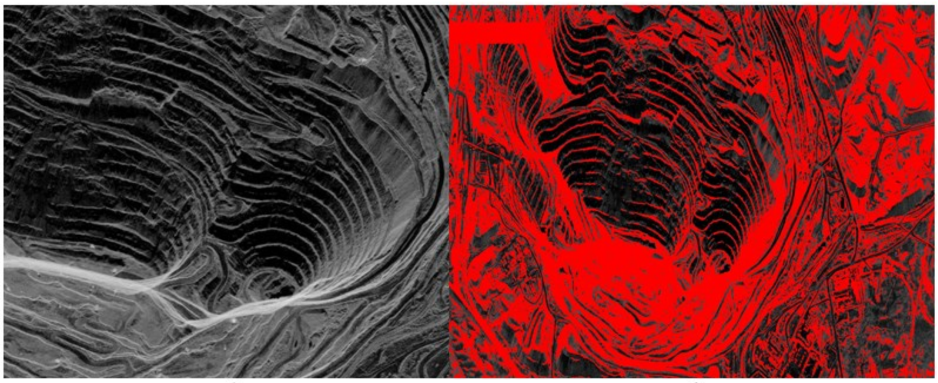


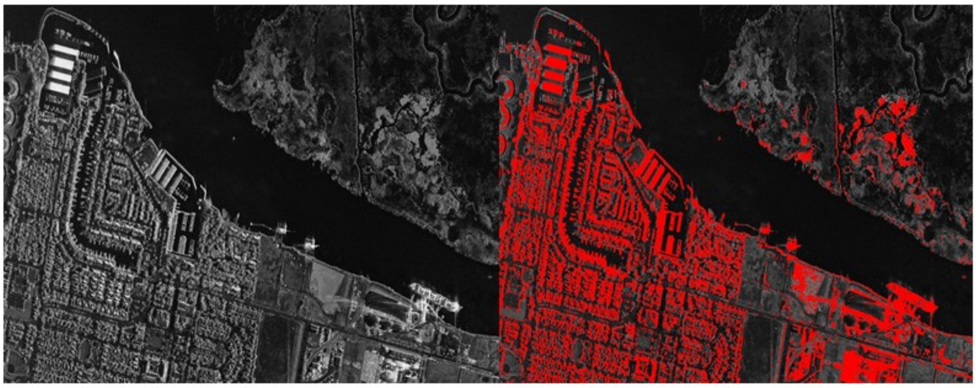
Fig. 9. Minimal Cut

The image is made into a graph, where two disjunctive sets are formed. One is connected to the source *s*, so the set of objects. And the other is associated with the mouth *t*, where the background seeds are. We obtained a minimal cut that splits the set into two sets based on the similarity of the pixels and the connection to the source *s* and the mouth *t*, see Fig. 9. This is then segmented, and the output is shown in the last figure [1, 2, 3, 5]. Here we can see that from the base image after segmentation using these methods, we have two sets that are correctly segmented. For segmentation we used for segmentation data from Open Gallery [1]. Segmented results obtained via Graph Cut method are visible on Fig. 12, 13, 14.



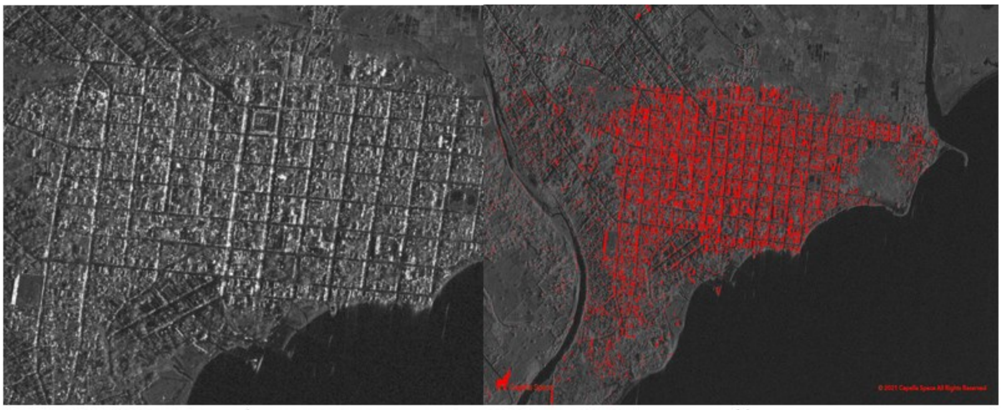
a) b

Fig.10. Data source explanation: a) Original data source: [15], b) Segmented data



a) b)

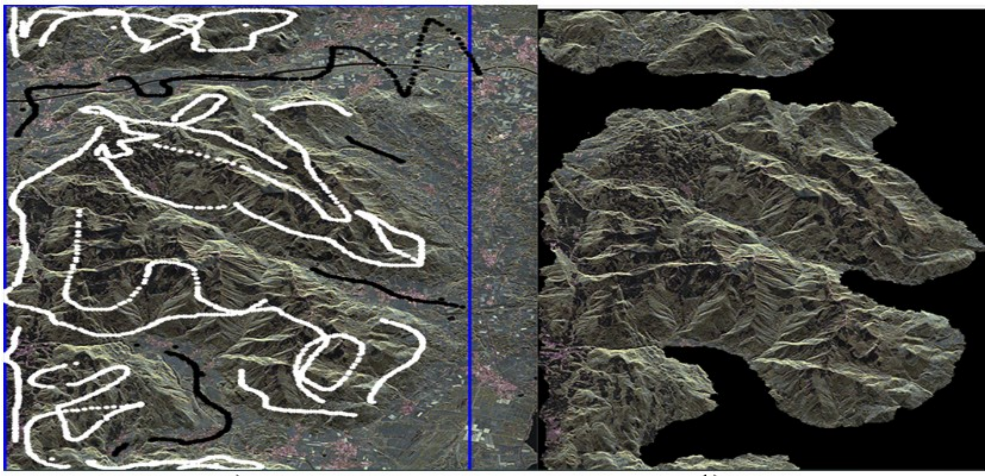
Fig 11. Data source explanation: a) Original data, source: [15], b) Segmented data



a) b)

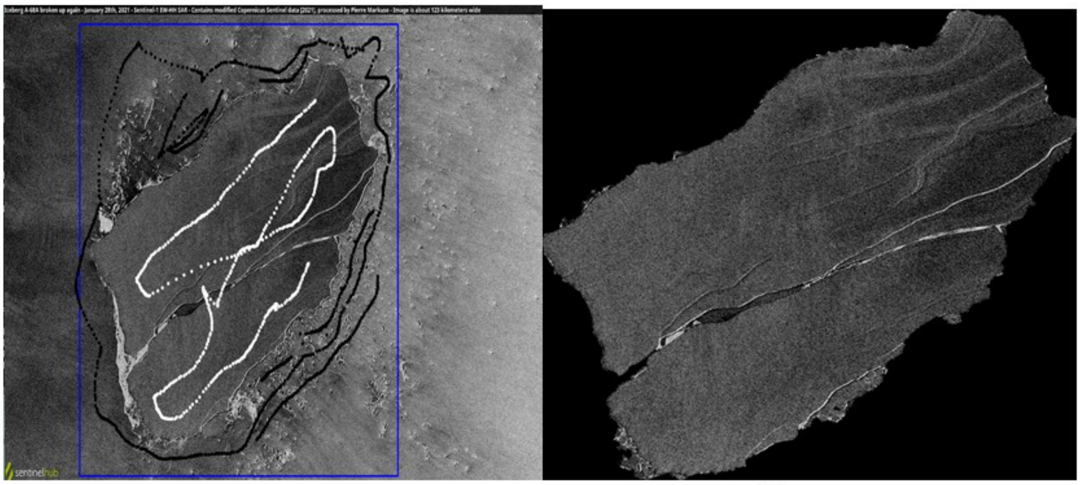
Fig.12. Data source explanation: a) Original data source: [15], b) Segmented data

Moreover, if we want to segment the whole concrete object, we can use Grab cut technique, which is focused on the boundary of the object. See the result bellow. First we detect the object and consequently we get the solo segmented object, Fig. 13, Fig.14.



a) b)

Fig.13. Data source explanation: a) Original data source: [15], with marks of object and background b) Segmented object



a) b)

Fig.14. Data source explanation: a) Original data source: [15], with marks background, b) Segmented object

6. Conclusions

In summary, this study highlights the crucial role that image processing and computer vision play in the defense and military sectors, particularly in the analysis of Synthetic Aperture Radar (SAR) data. The use of advanced image processing techniques is vital for enhancing the visualization and analysis of SAR data, which can be instrumental in applications such as object detection, target identification, and surveillance.

This contribution focused on the segmentation of SAR data to improve visual clarity and enable more precise image analysis. Specifically, two segmentation algorithms—Random Walker and Graph Cut—were implemented and optimized using C++ and Python. These methods allowed for the segmentation of SAR data into object and background regions, facilitating improved understanding of the imagery. Both techniques demonstrated good performance in handling SAR data and produced satisfactory segmentations under certain conditions.

However, both methods presented limitations. The segmentation process using Graph Cut and Random Walker is intensity-based, meaning the algorithms rely on pixel intensities to distinguish between object and background. In scenarios where SAR data contain noise, ambiguities at object boundaries, or small irrelevant artifacts, these methods can misclassify pixels, leading to segmentation errors. For instance, the edges of objects might not be accurately segmented, or small regions might be mistakenly classified as part of the object.

To address these limitations, the GrabCut algorithm was suggested as a more refined approach, especially when boundary accuracy is critical. GrabCut offers more precise control over object boundaries by iteratively refining the segmentation process, making it well-suited for applications where clear object delineation is essential.

In conclusion, while the Random Walker and Graph Cut algorithms offer robust solutions for general SAR data segmentation, their limitations in edge accuracy and intensity-based segmentation indicate that more sophisticated methods like GrabCut could provide improved results. Continued research and optimization of these techniques are necessary to overcome the challenges of SAR data segmentation, enabling more reliable image analysis in military applications. The implementation of these algorithms in custom-built software provides a flexible framework for future enhancements and integration of additional segmentation techniques.

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