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A Modified Markov Random Field and CNN-Based Approach for Aerial Road Segmentation

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Abstract: Artificial neural network-based systems currently demonstrate the highest accuracy among various methods for road detection and segmentation. However, for real-world applications such as autonomous navigation and military operations, significantly higher precision is essential. To address this requirement, this study explores a hybrid approach that integrates an Optimized Markov Random Field (OMRF) model with parameter estimation from Convolutional Neural Networks (CNNs) for detecting and segmenting roads from aerial imagery. The hybrid framework enhances performance by leveraging both pixel-level and region-level information, achieved by factorizing the overall likelihood into pixel-wise and regional likelihood components. The output images are classified into road and non-road segments, and the effectiveness of the proposed system is evaluated using confusion matrix metrics. The combined OMRF-CNN model achieves an impressive accuracy exceeding 99.5% for road detection in airborne images.

Keywords- Image Processing, Detection of Road Region, Segmentation of Road region, CNN, ANN, Neural Network, Markov Random field

1. Introduction:

India is at 51st position in the world when it comes to the nature of its roads. They are one of the most fundamental methods of transportation in India. The issue of drive path detection has been under technical scrutiny for a long time, and an enormous assortment of approaches can be found on review of the literature. Historically, the determination of road regions by humans often tended to depend on environmental analysis of sites.[1]

Until now, researchers have attempted to solve the road detection and segmentation problem. However, the developed algorithms are not able to handle all the scenarios that would probably arise in real time and hence it may not work in real-time varying environments. The algorithms have been continuously evolving as the technology getting more and more mature. It is precisely the reason why this problem is still open and needs to be addressed for meeting the next-generation navigation and disaster management. For example, the algorithm behaves well only on the images with highway roads (structured roads) and produces an unacceptable prediction for the pictures with roads in rural areas. Also, some of the existing algorithms have not been trained to consider curvy, snowy, rainy roads, and different daytime conditions which change the colors in the scene entirely. [2] [3]

Efficient Image-based methodologies have later been created and enhanced with many new features and applications by numerous specialists. Determining roads from images, and the subsequent road guides formed can be utilized as the foundation to update the centralized data information system. A fully developed, centralized data information system integrates five key essential components. 1. Dedicated Hardware, 2. Optimized Software, 3. Detailed Information, 4. Human Users, and 5. Proven Scientific Techniques. It can be used for future-oriented applications such as autonomous vehicle navigation because of its accuracy and efficiency. [4]

The fundamental task at hand is to ensure the combined functioning of the road network and road determination from the analysis of the satellite or aerial images, which can be performed by embedded programming. Most of the methodologies for retrieval of vital information rely on picture processing systems or order strategies or by the combined application of the above-discussed strategies. Many of the initial image processing methodologies use specific features to classify each independent image unit such as pixel or primary color image unit to an object tag. Certain classes of approach require an exceptional prior understanding of object features or class-conditional arrangement of pixel values. [5]

In a few critical applications, some input pictures need to undergo a step as pre-preparation. This process requires a high level of technical capability, and it is very much dependent on the competency of the person who analyses the data. Moreover, a semi-computerized approach is not suitable for continuous routing because it must overcome many issues, including the close resemblance of various other structures to roads on the aerial images. These issues further complicate the computerized approach and make it difficult to determine the actual route from them. The geographical conditions such as the presence of physical barriers, terrain and atmospheric conditions may also act as an impediment in detection as well as segmentation of Road Regions. [6]

Road detection and Segmentation also plays an essential part in Autonomous next generation Navigation Systems, self-driving platforms and emergency response mechanisms. A self-navigating vehicle using an Intelligent Transport System [ITS], exploring roads must have accurate data about the type of the landscape so as to facilitate smooth navigation from origin to destination. It is a fundamental and essential requirement to allow versatile robots and automatic navigation vehicles to explore self-sufficiently on our roads. ITS will also enable the vehicle to decide on reasonable controlling choices required to meet its mission objectives. A drivable road surface region should not contain any vehicles, walkers, cyclists, or different deterrents. Another fundamental aspect is the detection of road traffic signs used for controlling traffic. Road traffic signal detection often depends only on manual vision even in the assisted driving framework. It is a significant and challengeable assignment in an autonomous vehicle ecosystem. The utilization of visual sensors can help a great deal with this. [7]

Despite the enviable scientific developments in the area of high-resolution imagery from satellites and other aerial vehicles even today, the retrieval of reliable information from aerial snapshots continues to be a cumbersome task. The multitude of applications of this data reinforces the need and importance of analyzing all the available data. Unfortunately, the technology for analyzing all of these available high-resolution images has not been able to match up to this need. As of today, much of the work of analyzing the images and deriving meaningful information from the same is still primarily conducted as a manual activity. Not only is this expensive and time consuming, but also error prone. Because of the amount of these errors blended with the available methods, there is a huge demand for faster and reliable methods that can analyze the complete dataset automatically without any manual interventions. [8]

In the earlier days during the aerial monitoring of the earth surface, the drive path identification and its accurate segmentation presented an arduous challenge. Numerous techniques were applied to mitigate the problematic challenges faced by the industry, and it started with the texture analysis methodologies. [9] They were put in place to identify the required interested targets, especially the drive path from the airborne snapshots. The determination of the necessary picture information inherently will entirely be based on the typical application context. [10] The proposal of this paper project is for the development of a new simplified algorithm based on advanced optimized MRF and CNN models. The paper as mentioned earlier is conceptualized to systematically analyze the aerial snapshots used for detection and segmentation of road targets and in turn reduce the need for especially skilled analysts, skill sets, reduce the overall time needed, and increase the application accuracy.

2. Implementation:

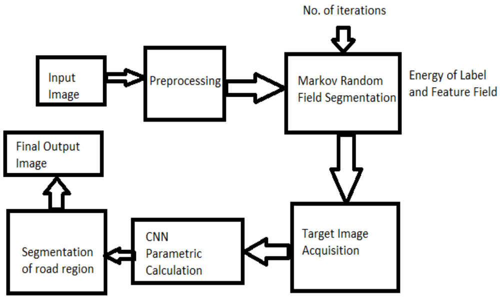

Fig. 1 – CNN-OMRF System Block Diagram

In the diagram Fig. 1 the proposed system block diagram is shown.

The algorithm is shown below:

- Start the Image processing Hybrid CNN-OMRF Working Model in Desktop computer using MATLAB development environment.
- Input Image is acquired for computation purposes. (Image to be Segmented).
- Input image is converted to matrix vector format using the Im2stackvectors is a function defined in MathWorks to convert an image to vector format. Improve image quality by double function, set variables for Potential Iteration (Maximum Iteration) for segmentation
- ICM Function is invoked for MARKOV Random Field Segmentation,
  - ➢ K-means clustering algorithm is applied, so that it is possible to perform efficient color mapping and this makes segmentation a lot easier.
  - ➢ GMM function is invoked in order to compute Image parameters such as mean, variance, energy potential calculations are performed.
  - ➢ Image Parameters is then fed to energy of feature field function (energy parameter determined in the image processing to segment, classify and detect segmented regions),
  - ➢ Image Parameters are also fed to energy of label field function (Markovs segmentation image segmentation part is performed, which is given in Neix function (Neix function assigns energy potential of the image for better understanding of road and non-road region used in CNN Parametric calculations and final region definitions) Image segmentation is performed through energy, potential calculations of the image pixels and iterations-based assigning of logic 1 and 0 to output image which is then passed through the CNN.
  - ➢ These outputs of energy of feature field function and energy of label field function are combined using the formulae to give final value for segmentation output and stored in the memory to pass it to the main program where the segmentation is verified using CNN parameter computations
- Combined Segmented Image is stored in the memory once the targeted number of iterations is reached.
- Re-acquisition of Image in the main code is done for computation of CNN parameters. By comparing the segmented

image and grayscale target image, standard formulas are applied to calculate the below mentioned parameters.

- TruePositive;
- TrueNegative;
- FalsePositive;
- FalseNegative
- ImageSpecificity
- ImageSimilarityIndex
- ImageSensitivity
- ImagePrecision
- F-Measure
- TotalSegmentationError

Note: Definition of the various computed parameters as well as the total segmentation errors are described in detail in the section 4.2.1 and 4.2.2.

- Convert Output image to black and white for final segmentation image display.
- Display the Calculated parameters on the MATLAB Command window.
- End the Image processing Hybrid CNN-OMRF Working Model in Desktop computer using MATLAB development environment.

Massachusetts Road Dataset—a high-resolution aerial dataset comprising 1,171 images (1500×1500 px), split into 1,108 training, 14 validation, and 49 testing images

3. Results

In this section results are presented, Fig. 2, Fig. 3 And Fig. 4 are the input images which are tested on our software implementation.

Fig. 2: Road Input Image (Aerial Image 1).

The above Fig. 2 demonstrated as the input image taken for the segmentation and detection of the road region. This image basically shows the U-turn trajectory and it is being improved with the proposed algorithm as seen in below Fig. 3.

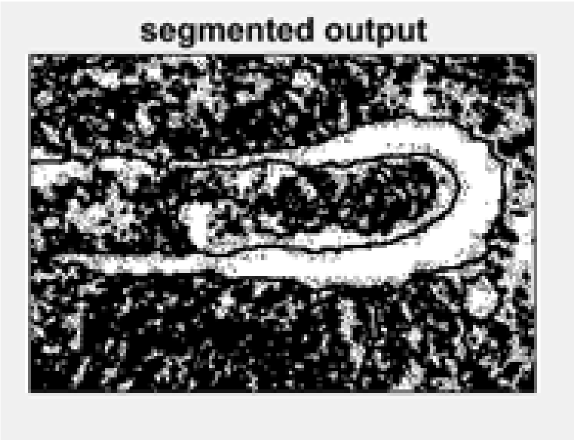

Fig. 3: Markov model of iteration count (image 1)

The Fig. 3 shows that after completion of the successful iteration count in the proposed methodology the image is then converted into a black & white image. The road region shows the continuous blank line in the form of road, which gives a better idea of the road for navigation purposes. The accuracy is 99.7% by the above discussed formulas. Now more images are taken in order to check if the detection and segmentation is working correctly.

Fig. 4: Markov model of iteration count (image 2)

Fig. 5: Proposed Hybrid CNN –Random Field model for aerial image 2

In Fig. 4, the input image is shown and its output in Fig. 5. Once more, for assessing the exhibition of proposed CNN based Markov random field model, the second picture is sustained into MATLAB code. The info picture is handled for cycle for iteration no. 20. Last segmented picture accuracy estimation of 99.75 with SI as the similarity index 99.7.

Fig. 6: Aerial input image 3

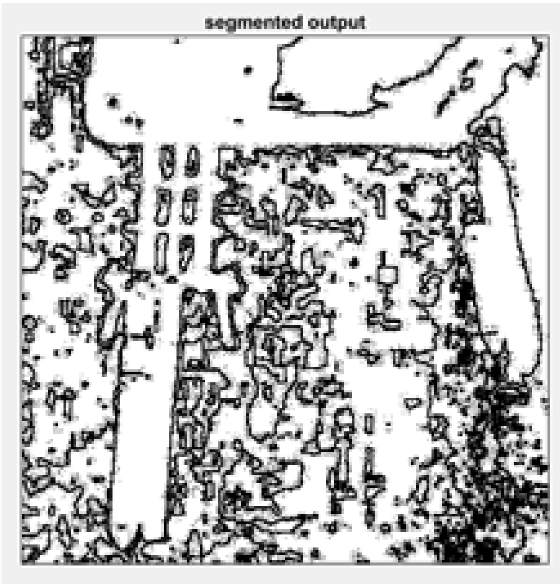

Fig. 7. Proposed Hybrid CNN –Random Field model for aerial image 2

Now for another input picture shown in Fig. 6 and its output in Fig. 7, the accuracy calculated is 99.9 with scope of 99.72 and affectability 99.6 is accomplished. Through assessment of results it is seen that proposed methodology performs viably.

In particular, a linear model for road recognition is used by this method. It achieves good performances for a clear, defined street, but its frequency of skipped or false detection is quite strong when confronting irregular roads or obstacles on the road ahead. Due to the impact of lighting, reflections and dynamic barriers, though, it is difficult to achieve a complete precision in any classifier and too many roads are broken into non-road zones. The benefit of using the MRF is shown by a comparison of the results of proposed & CNN. The accuracy for only CNN is around 97-98% with a high execution complexity and in the proposed technique, the accuracy is almost 99.7%

4. Conclusion:

Image processing is one of the emerging fields with many practical research opportunities. The completed study showcases the effectiveness and efficiency of bringing multiple proven techniques to resolve the problems using hybrid algorithms. The computed Accuracy of minimum of 99.7% was observed for more than 100 images used for testing this proposed algorithm. It is highly Accurate, Clear, Simple and Efficient for road detection and segmentation applications. This proposed algorithm will be constructive in access to remote areas where the road is not yet mapped already. It is beneficial in existing road detection as well as its segmentation for urban planning & infrastructure development. The efficiency of the algorithm is remarkably high, even with minimum iterations thereby reduces the execution time. The study confirms the algorithm is straightforward to use and apply on real-time applications. It will also be advantageous for autonomous navigation during extreme weather conditions like flood, landslide, earthquake, fires etc. to ensure safe navigation of vehicles through the road. The very same algorithm and model developed using a desktop computer using MATLAB for road detection under this research can be used for detection and segmentation of rivers, oil pipelines, etc. from aerial images.

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