Delineation and Extraction of Information on Farm-to-Market Roads (FMR) using Very High-Resolution (VHR) Satellite Image

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Abstract

This study introduces a semi-automatic method for extracting farm-to-market roads (FMRs) using very high-resolution (VHR) satellite imagery with only RGB bands. The workflow combines edge detection, thresholding, and morphological operations with vector-based transect analysis to delineate roads and estimate width information. Applied in Nueva Ecija, Philippines, the method produced reliable results despite the absence of multispectral data and processed large images in under a minute. This speed makes the approach practical for monitoring FMR construction, especially in remote areas where site visits are difficult. While VHR imagery provides accuracy and frequent coverage, its use is limited by cost and licensing. To address scalability, the method can be adapted for medium-resolution sources such as PlanetScope or Sentinel-2, with expected trade-offs in precision. Future comparison with UAV-based monitoring may further clarify the balance between cost, coverage, and accuracy, strengthening its application in broader infrastructure planning.

1. Introduction

1.1 Background of the Study

Farm-to-market roads (FMRs) serve as vital infrastructure that connects rural agricultural communities to markets, services, and broader economic opportunities. Their development is fundamental to enhancing transportation accessibility, reducing logistical costs, and promoting sustainable rural growth. In particular, the delineation and planning of FMR networks benefit greatly from advancements in geospatial technologies (Greenstein, 2011). As such, one of the DigitalAgri Project (Phase I), a collaborative project between the Department of Agriculture Bureau of Agriculture and Fisheries Engineering (DA-BAFE) and Philippine Space Agency (PhilSA), goals is to explore the feasibility of Very High-Resolution (VHR) images in extraction or detection of FMRs through remote sensing applications.

Road extraction from remotely sensed imagery is a fundamental task in geospatial analysis, supporting applications such as vehicle navigation, urban planning, and updating GIS databases (Chen et al., 2020). For optical images, road extraction generally focuses on three key components: road areas, road centerlines, and road boundaries. Methods for extracting these features can be grouped into three categories: morphological feature-based, handcrafted feature-based, and automatic feature extraction approaches, the latter of which are primarily driven by deep learning (Chen et al., 2020) mainly for non-commercial and mid-resolution images.

High-resolution satellite imagery provides timely and accurate spatial data that improves the precision of mapping, site assessment, and planning efforts. This integration of geospatial data enables stakeholders to identify optimal routes, prioritize investments, and monitor road conditions effectively, thereby supporting data-driven decision-making for rural infrastructure development (Mukhopadhyay et al., 2024).

In optical satellite remote sensing, achieving higher spatial resolution necessitates trade-offs in other sensor specifications, particularly spectral resolution (Carleer et al., 2005). For instance, the high-resolution satellite sensors in this study capture only the visible spectrum in RGB bands, lacking the broader spectral range of multispectral or hyperspectral data. Information from RGB imagery can be extracted through common image analysis techniques such as image segmentation and morphological operations. While these concepts are often used in contexts where the distinction between the background and foreground is apparent in the input image, this paper applies these methods in delineating roads from a complex image input (e.g. VHR, high terrain variability) through a systematic approach. Through these efficient computation approaches, this paper leverages spectral restrictions of VHRs for timely road extraction and analysis.

1.2 Study Area

Nueva Ecija, the pilot site for the DigitalAgri Phase I Project, is a province located in Region III (Central Luzon), with an area of 5,689.69 sq. Km. The province is mostly known for cultivating crops such as rice, corn, and onion among others. For an agricultural province, the development of FMR plays a critical role in enhancing agricultural productivity and market accessibility.

FMR serves its purpose of providing safer and more efficient routes for transporting agricultural goods. This infrastructure improvement enables farmers to transport their agricultural products more quickly and with greater ease of delivery, while also minimizing logistical challenges. As a result, access to major commercial centers within the province is significantly enhanced. Such projects are part of broader national strategies aimed at supporting the agricultural sector. By prioritizing road connectivity in agricultural regions, the Philippine government aims to reduce the cost of transporting farm products, stabilize food prices, and improve the availability of fresh goods in both local and urban markets. Improved accessibility not only benefits the immediate farming communities but also contributes to the economic vitality of neighboring areas by fostering more consistent and efficient transportation of agricultural commodities (Tecson, 2022).

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Specifically, the number of completed FMRs in Nueva Ecija as of 2024 was at least 300, based on the data provided to the research team by the Department of Agriculture Bureau of Agriculture and Fisheries Engineering (DA-BAFE). According to the general guidelines of the DA-FMR Development Program, the minimum width of a one and two-lane road is ~3m and ~5m respectively, and a minimum length of 1000m. The FMRs are mapped over the study area in Figure 1.

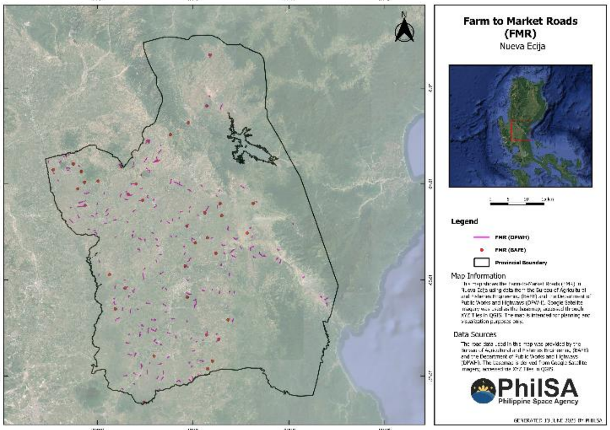

Figure 1. Map of Nueva Ecija showing the Farm to Market Roads.

2. Data and Methods

The semi-automatic delineation of FMR would require the VHR image, in this case, Blacksky image, and the proposed FMR centerline shapefile. The image processing workflow (Figure 2) starts with the preprocessing which consists of reprojection and application of filters. This will be followed by edge detection and thresholding; for the improvement of road delineation, morphological operations were applied to the output of the edge detector. For the final road raster, cleaning such as small island removal and clipping was done. To extract the width information, transects generated using the input FMR centerline will be clipped by the final road raster.

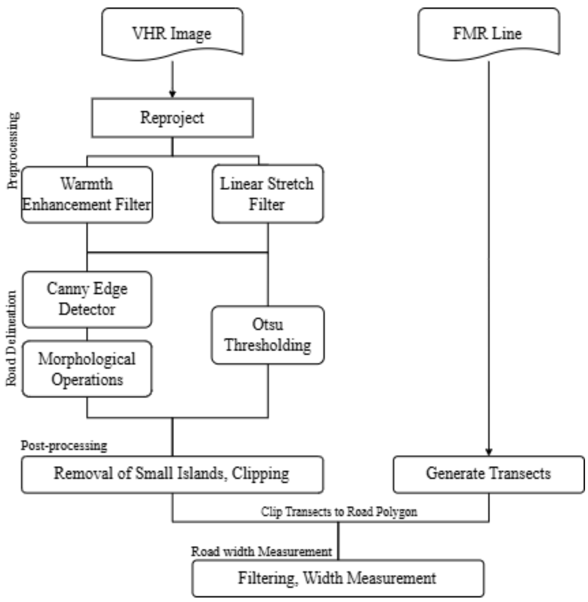

Figure 2. Methodological framework for FMR delineation using VHR.

2.1 Very High-Resolution (VHR) Images

Recent progress in remote sensing technology has facilitated the development of multiple platforms which can acquire very high-resolution (VHR) imagery (Zhao et al., 2017). Such imagery provides detailed visual representations of ground surfaces, capturing subtle features like object boundaries, geometries, and textures. This level of detail makes VHR data particularly useful in applications such as land cover analysis, infrastructure planning, and road network extraction (Zhiyong et al., 2021).

Despite the advantages of enhanced spatial detail, increased resolution does not necessarily translate into improved accuracy in feature detection tasks. VHR images often exhibit significant intraclass variability, which can pixelate the distinction between visually similar objects such as roads, rooftops, or other manmade structures thereby complicating classification and segmentation efforts (Pacifici et al., 2009). Furthermore, due to the smaller pixel size and dense pixel arrangement characteristic of VHR imagery, the spatial relationships among adjacent pixels become more complex, posing additional challenges for object delineation.

These limitations are particularly pronounced in temporal change detection using pairs of VHR images. While finer spatial detail offers more precise localization of changes, it also tends to introduce noise commonly manifested as a salt-and-pepper effect in change detection outputs due to pixel-level inconsistencies and misclassifications (Demir & Bruzzone, 2015). As a result, the effective utilization of VHR data demands advanced processing techniques and robust algorithmic frameworks, as higher spatial fidelity alone does not ensure superior analytical performance.

Several studies have demonstrated the effectiveness of VHR satellite imagery for road mapping and monitoring applications. Ouled Sghaier and Lepage (2016) developed a novel road extraction approach from very high-resolution optical images using texture analysis and beamlet transform, applying their methodology to GeoEye-1 imagery (0.58m resolution) of Port-au-Prince, Haiti. Their method successfully combined local texture information with global spatial relationships achieving completeness values of 75-90% and correctness values of 73-93% across different urban environments.

Singh and Garg (2013) proposed an automatic road extraction method using adaptive global thresholding and morphological operations on high-resolution satellite imagery. Their approach demonstrated robust performance in suburban areas, achieving 95.32% completeness and 96.52% correctness by effectively handling illumination variations and different pavement materials through histogram-based segmentation.

In this study, BlackSky images with a spatial resolution of 0.83m were used. Its system captures multispectral data: RGB bands, namely, blue (450–520 nm), green (500–590 nm), and red (590–700 nm), and a panchromatic band covering 450–700 nm. Each image scene typically covers an area of about 5 km × 5 km. BlackSky's constellation offers high temporal coverage, with up to 15 satellite passes per day, allowing for frequent monitoring of areas of interest.

Use of BlackSky imagery may be subject to licensing and copyright restrictions depending on the data provider or commercial agreements.

2.2 Segmentation Methods

Segmentation is the first step to distinguish the potential road surfaces from the surrounding environment by converting raw imagery into simplified categories such as road and non-road areas. It reduces data complexity and highlights features of interest that can later be refined. Ding and Goshtasby (2001) described the Canny Edge detector as a method that can locate sharp intensity changes, classifying a pixel as an edge if the gradient magnitude of the pixel is larger than those of pixels at both sides in the direction of maximum intensity change. This paper uses scikit-image canny edge detector which has three tunable parameters: width of the Gaussian, and the low and high threshold for the hysteresis thresholding. The appropriate configuration of these parameters played an important role in achieving optimal edge output in addressing the challenges posed by the image complexity.

On the other hand, Wang et.al. (2022) defined Otsu Thresholding as a method used in image processing to automatically determine the optimal threshold value for converting a grayscale image into a binary image. It involves iterating through all threshold values and calculating a measure of spread for the pixel levels on each side of the threshold. The goal is to find the threshold value where the sum of foreground and background spreads is at its minimum.

2.3 Morphological Operations

The role of morphological operations extends beyond mere cleanup; they serve as essential tools for enhancing the quality of the segmented road and non-road regions following initial detection by segmentation algorithms. These operations are pivotal in rectifying imperfections in the segmented output by bridging minor discontinuities, smoothing jagged or irregular road boundaries, and eliminating isolated noise pixels that may have been misclassified. According to Chudasama et al. (2015), morphological operations work by manipulating image shapes to remove defects while preserving the overall structural integrity of the objects within the image. Among the most prevalent morphological techniques are Erosion and Dilation. Erosion functions by stripping away pixels from object boundaries, effectively shrinking the size of segmented shapes. Conversely, Dilation adds pixels to object boundaries, which can expand the object area.

When used in succession, these operations produce two important composite procedures: Opening and Closing. Opening, which involves erosion followed by dilation, is particularly effective in removing small unwanted objects or noise from the image. Closing, which entails dilation followed by erosion, is applied to fill in small holes or gaps within the segmented objects, reinforcing their continuity. It is important to note that the effectiveness of these operations heavily depends on the size and shape of the structuring element, often referred to as the window, as it determines the scale at which features are either removed or preserved.

2.4 FMR width extraction

The algorithm takes in two inputs: a raster image and a centerline vector. The raster image is a very high-resolution (VHR) satellite image, while the centerline vector may either be sourced from existing road layout plans or manually digitized by the user. These inputs undergo a structured processing workflow designed to facilitate the semi-automatic extraction of Farm-to-Market Road (FMR) width information. The process starts with preprocessing, which ensures the spatial alignment and enhancement of the image data. This is followed by the generation of an initial road delineation in the form of a binary raster, representing road and non-road features. The final step involves the extraction of road width measurements by analyzing the intersection of the processed raster with transects generated along the input centerline. This structured approach allows for a repeatable and efficient method of deriving road width information using minimal manual intervention.

2.4.1 Preprocessing: The image input undergoes reprojection according to the target Coordinate Reference System (CRS), ensuring spatial consistency across all geospatial layers used in the analysis. This reprojection step also applies to the centerline vector, aligning both inputs to the same CRS to facilitate accurate overlay and processing.

Because VHR images are inherently large, data-heavy, and often contain more spatial information than required for a single analysis, the image is clipped to the extent of the centerline vector, with an added buffer to ensure that no portion of the actual road is excluded. This buffering is especially important in cases where the road alignment may shift slightly within the image frame. To enhance the visual and analytical quality of the imagery, two preprocessing enhancements are applied: warmth enhancement, which increases the red values to emphasize bare soil and infrastructure elements, and linear stretching, which adjusts the distribution of pixel intensity values to improve contrast and highlight relevant features. Figure 3 shows the image after these filters have been applied.

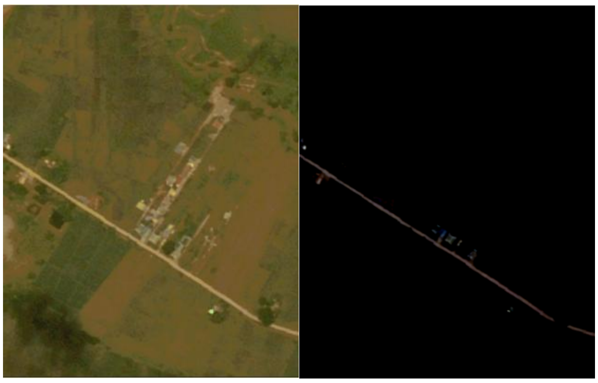

Figure 3. Result of warmth enhancement (left) and result of linear stretching (right).

2.4.2 Road delineation: Delineation of road was done by mixing segmentation methods and morphological operations, leveraging the image’s intensity values and the road’s geometric properties, respectively. Segmentation methods include Canny edge detector and Otsu thresholding. Canny edge detector is a widely used edge detection operator known for its optimality according to the three criteria of good detection, good localization, and single response to an edge (Ding and Goshtasby, 2001), allowing for the detection of road edges with precision even in complex scenes. Otsu thresholding converts a grayscale image to a binary image by determining an optimal threshold that minimizes intra-class variance—in this paper, classifying features into road and non-road categories. These segmentation techniques complement each other by capturing both boundary and intensity-based characteristics of road surfaces.

Morphological operations such as dilation followed by erosion were applied to the edge raster, effectively transforming edge outlines into solid binary masks of road and non-road features. This step smoothens the road shapes and fills in minor gaps that may have resulted from edge detection. The outputs from segmentation and morphology were then combined to produce the initial binary raster. Additional cleaning processes, including small island removal and clipping, were performed to eliminate noise and retain only the relevant road segments. Figure 4 shows the resulting binary raster after applying the edge detector and Otsu threshold, highlighting the effectiveness of this combined approach in isolating the FMR features from surrounding elements.

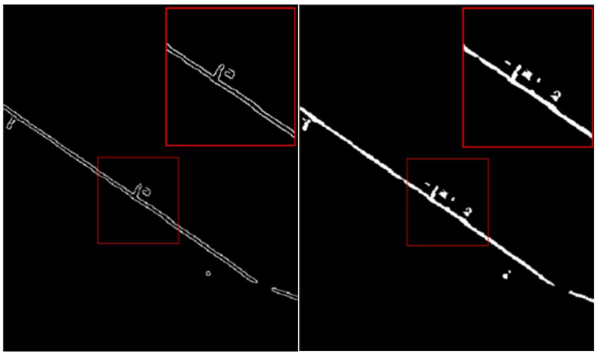

Figure 4. Result of canny edge detector (left) and result of Otsu threshold (right).

2.4.3 Width Measurement: The width is derived by using the input FMR centerline vector to generate perpendicular transects, which are then clipped using the vectorized binary raster representing the delineated road. Each transect intersects the binary road raster, and the length of the clipped portion is computed as the road width at that specific location. These resulting transect lengths are then filtered by applying a threshold range to remove any values that fall outside the acceptable limits for a standard two-way Farm-to-Market Road. This filtering process is guided by the Design Standards for Tourism and Farm to Market Roads Department Order (DPWH, 2014), which mandates a minimum roadway width of 4 meters. To accommodate potential deviations resulting from image noise, spatial inconsistencies, or the effects of vegetation and dirt on road edges, an adjusted threshold range of 3.5 to 6 meters was defined. This tolerance ensures that the measurements remain realistic and within a margin of error appropriate for the image resolution and processing method.

3. Results and Discussion

3.1 Delineated FMR and Width Information

The resulting output is a binary raster that classifies road features in white and non-road areas in black. This classification is based on pixel intensity values and spatial structure derived from the segmentation and morphological operations described earlier. In the resulting image (Figure 5, left), some sections of the road appear incomplete or disconnected due to visual obstructions such as tree canopies, which cast shadows or fully conceal parts of the road surface. On the other hand, certain areas appear to branch out unnaturally – these are typically caused by adjacent features such as exposed soil, tin roofs, or dirt paths that reflect similar intensity values to the road surface, especially under direct sunlight. Despite these challenges, the method proves capable of identifying and classifying road segments even with limited spectral information, relying solely on RGB bands.

The extracted transects, shown as red lines in Figure 5, represent the sampled segments used to estimate road width. However, not all transects are retained in the final output. Some are filtered out because their lengths fall outside the expected range for standard FMRs – either too long due to branching misclassifications, or too short due to occlusion or noise. The filtering step is necessary to avoid reporting misleading measurements. The completeness and accuracy of these transects are highly dependent on the quality of the input VHR imagery. Factors such as haze, cloud cover, and image sharpness can introduce uncertainty in the road boundary delineation process. Additionally, natural elements like dirt, vegetation, and overgrowth encroaching along the road edges can cause the extracted road width to be underestimated. This is particularly true in rural areas where maintenance is infrequent, and road edges gradually blend into the surrounding environment. These limitations highlight the importance of selecting high-quality imagery and possibly integrating auxiliary data to improve road detection in future applications.

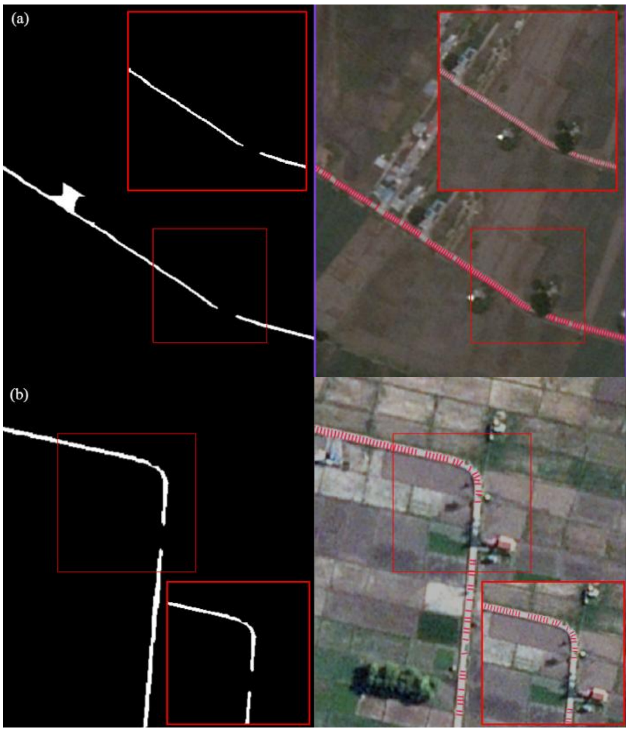

Figure 5. Delineated FMR (left) and filter transects (right) in (a) Brgy. Sta. Arcadia, Cabanatuan City, Nueva Ecija; and (b) Brgy. Bravo, General Mamerto, Nueva Ecija

3.2 Monitoring capabilities

The approximate run time of this method is less than a minute, which is fast considering that the file size of one image with approximately 5 x 5 km is averaging 250 MB. This processing efficiency makes it suitable for use in monitoring applications where time and resource constraints are critical. As reported by the DA-BAFE, the construction of an FMR typically spans between 3 to 6 months and requires at least three physical monitoring visits throughout this duration. These monitoring activities involve assessing the constructed road's length, verifying the road width and materials used, and checking if the work progress aligns with the approved project workplan. Traditionally, these inspections are carried out by designated engineers or officers who must visit each site, often traveling considerable distances, particularly in rural or remote areas. These visits can be both time-consuming and resource intensive. By applying the workflow developed in this study using VHR satellite images with high temporal resolution, it becomes feasible to monitor the development and compliance of FMRs more frequently and efficiently. This capability is especially beneficial for remote areas where accessibility issues commonly delay inspections, making satellite-based monitoring a practical and cost-effective alternative.

The use of very high-resolution (VHR) imagery provides clear advantages in terms of revisit time and level of detail, but it also comes with limitations. The main concern is the cost of acquiring commercial images, which can make large-area applications difficult to sustain. A comparison with unmanned aerial vehicles (UAVs) shows a trade-off: UAVs can capture images at finer resolution and can be scheduled more flexibly, but they require more manpower, planning, and expense, especially for wider or harder-to-reach areas. Satellites, on the other hand, cover larger extents at once but require licensing agreements. Even with these constraints, the high frequency of VHR satellite passes makes them practical for monitoring farm-to-market roads in remote places where UAV surveys may not be feasible.

4. Conclusions and Future Work

This study presented a semi-automatic method for delineating farm-to-market roads (FMRs) from very high-resolution (VHR) imagery using only RGB bands. The workflow combined segmentation methods and morphological operations with vector-based analysis, producing reliable results in extracting road features, and estimating road width information. The approach offers a faster and less strenuous alternative to manual digitization, showing that useful information can still be derived even when higher spectral detail is not available. The method also demonstrated value for monitoring, as it can process large image files in under a minute, making it practical for repeated use during construction monitoring or project evaluation.

While the use of VHR imagery provides clear advantages in accuracy and revisit rate, it also presents limitations due to cost and licensing. A comparison with UAV imagery highlights the trade-offs between methods: UAVs can achieve finer detail and flexible timing but require more resources and planning, while satellites provide wider coverage with more consistent revisit schedules. For remote or inaccessible areas, VHR satellites remain a practical option for efficient monitoring.

Future work should expand the method by testing its adaptability to medium-resolution sources such as PlanetScope (~3 m) and free-access Sentinel-2 (~10 m). Although a decrease in resolution will likely affect the precision of road width estimates, these tests will show how well the workflow can be scaled in situations where VHR imagery is not available. Further comparison between UAV- and satellite-based monitoring approaches can also provide insights into balancing cost, coverage, and accuracy. These improvements will help make the workflow more versatile and applicable to a wider range of operational and research settings.

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