Development of a Methodology to Map Railway Lines and Surrounding Land Use Using UAVs

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Abstract

High accurate railway maps and terrain information (Digital Elevation Models) is a major concern for future railway constructions and railway lines development.The mapping of railway line using ground based surveying techniques istime consuming and problematic.Unmanned Aerial Vehicles (UAV) technology has revolutionized the aerial photogrammetric mapping due to its low cost and high spatial resolution. It enables mapping the land use with greater accuracy in both 2D and 3D. The "DJI Phantom 4" drone was selected as the UAV platform to acquire image data. In this study, we have developed a fully automated and highly accurate engineering approach for detecting land use and railway line, which is based on textural information from orthophoto and elevation information (Digital Surface Models)obtained from the drone.The Pix4D software was used to develop the orthophoto and a Digital Surface Model (DSM) and the DSM was validated by using the ground control points.The rule sets knowledge-based classification method in object oriented classification was used to classify the land use and railway with the use of "eCognition" software. Finally, the results were compared with digitize land use layer to validate the results, and obtained overall accuracy of 90.15%.

Keywords: DSM, Land use mapping, Object Oriented Classification, Orthophoto, Photogrammetry

1. Introduction

Unmanned Aerial Vehicles (UAV) technology has radically changed the aerial photogrammetric mapping and able to compete with traditional acquisition platforms, such as satellite and aircraft, due to low operational costs, high operational flexibility and high spatial resolution of the imagery. Also data can be acquired more rapidly from UAV platform than the conventional platforms and it has the option of alternating the sensors working in visible, infrared, and microwave wavelengths. Many remote sensing applications have benefited from the use of UAVs. In urban monitoring and planning, UAV images are used to generate 3D building models, map generation, PV inspections, change detection and map updating in newly built areas. Biomass estimation, crop monitoring and precise farming are some applications in the field of forestry and agriculture mapping [1]. Environmental monitoring includes fires, energy fluxes, global glaciers and snowfields and disaster mapping such as landslides and floods. The fields such as coastline management, transport planning (traffic monitoring), oil and gas exploration, Quarries and minerals (Volumetrics and Exploration) archaeology and heritage mapping and cellular network planning are also benefited by UAV technology [2].

UAV photogrammetry has improved and facilitated the creation of an advanced tool for photographic measurement compared with the present day conventional methods of photogrammetry [2]. The major components of a UAV include an unmanned aircraft, a transmitter, a communication link, an image sensor such as a digital or infrared camera and mission planning. UAV photogrammetry can also be integrated with a LiDAR system.

UAV Photogrammetry facilitates both autonomous and semi-autonomous remote controlling and ensures the accuracy of an approximate 1cm to 2cm. Further, it creates new opportunities for application in close range domains by combining terrestrial and aerial photogrammetry. UAV Photogrammetry enables application in both small scale and large scale, with varying or similar system costs, depending to an extent on the intricateness of the system.

Object oriented image classification involves identification of image objects, or segments, that are spatially adjacent pixels of similar texture, color, and tone compared to conventional pixel based classification approaches, which utilize only the spectral response. Image objects contain additional information, such as object texture, shape, relations to adjacent regions. The data like existing GIS layer or digital surface models (DSM) can easily be integrated and used in the classification process. Rule sets knowledge- based method in object oriented classification is important because it impacts significantly on the accuracy of the object oriented classification result. The classification rule sets can be derived from spectral indices, geometry and texture.

The mapping of railway line is currently done by ground based surveying techniques. The total route length of railway line in Sri Lanka is 1569 km. It is very much time consuming to map such a length using ground surveying techniques. Therefore, UAV Photogrammetry will give a new efficient approach for mapping of railway lines.

2. Methodology

2.1 Study Area and UAV Used

A length of 400 m along the railway line in Panadura, Sri Lanka and a stretch of 0.1128 km^2 along the railway line was selected as the study area which is shown in Figure 1. When selecting the area, one of the main considerations was the variation of land cover type which is a combination of vegetation and the house buildings.

The "DJI Phantom 4" was chosen considering the affordability and mobility. The built-in camera on the Phantom 4, with 12 megapixels of resolution, is able to capture very high quality images with maximum image size of 4000 x 3000 pixels. Also, the drone itself has multiple sensors, dual GPS and GLONASS navigation, an advanced Visual Positioning System (VPS), and automated subject-tracking and obstacle avoidance [4].

Figure 1 - Study Area

2.2 Flight Planning and Image Acquisition

Map Pilot for DJI, a mobile application was used for Flight Planning. A fully autonomous flight was executed by using this application. The application combines advanced features like automatic flight path creation, overlap management, speed management, multi flight coordination, etc. The area of interest, flying altitude, overlap, maximum speed, and etc. were given manually to the application. The exposure location and flight paths were automatically calculated according to the given flying altitude and image overlap [5].

Flying altitude was set to 100 m above ground level. Both side overlap and forward overlap were set to 80% to provide more key points as possible for accurate photogrammetric processing. A total of 181 photographs were taken by DJI Phantom 4 with an average Ground Sampling Distance (GSD) of 4.3 cm by two successive flights. All the images were produced in JPEG format and were processed together to obtain DSM and orthophoto.

2.3 Ground Control

Kinematic GNSS Positioning was known as the most efficient and effective way of establishing ground control in modern surveying applications, as it encounters the required details in most situations [6]. For this project, newly marked 13 ground control points were used which was measured by "CORSnet". It was established to broadcast RTK corrections and RINEX data for post processing covering the Western Province of Sri Lanka.

2.4 Point Cloud and Mesh Generation

In initial processing, Pix4D extract the accurate key points in individual images using SIFT algorithm. The key points were used to find matches between the images. From these initial matches, the software runs an Automatic Aerial Triangulation (AAT) and Bundle Block Adjustment (BBA) algorithms. The software consists of a camera parameter database for common cameras used for aerial photography. In processing, the camera parameters were optimized by a self-calibrating bundle adjustment using the key points as well as GCPs [7].

As the result of initial processing, camera parameters, location and orientation were computed with the matched key points and sparse cloud was generated. The sparse point clouds generated consists only of points that were successfully matched and verified along the multiple images. In fact, there were potentially many more matches that result to a much more dense point clouds.

The Densified Point Cloud is a set of3D points that reconstruct the model. The X, Y, Z position and the color information are stored for each point of the Densified Point Cloud. A scene can be digitally reconstructed by using the automated dense image matching techniques by starting from the known exterior orientation and camera calibration parameters. A dense stereo matching algorithm in the software is able to extract dense 3D point clouds with a sufficient resolution to describe the object's surface. Millions of points with known ground coordinates were generated during this phase. The generated point cloud was then triangulated to create a mesh [8].

2.5 DSM and Orthophoto Generation

The dense point cloud was interpolated to form a triangulated irregular network in order to obtain a digital surface model. A Digital Surface Model can be considered as a digital 3D representation of an area by elevation. A DSM represents a surface model as a regular grid of height values. Each pixel of the raster image was assigned to represent the elevation of the ground location at that pixel [8]. An orthoimage is generally a photo map which is geometrically corrected and having a uniform scale.

2.6 Classification of Surrounding Land use and the Railway Line

The initial step of the knowledge based classification was the segmentation of an image into isolated regions represented by simple unclassified image objects, known as "image object primitives". The necessary elevation information needs to be represented to get the most realistic image objects. The multiresolution segmentation algorithm was utilized to create image objects because it organizes the image into regions with similar pixel values.

The classification task was carried out using "eCognition" software. An assumption, that "the buildings and trees were always elevated" was made. Further, the study area did not experience much change in terrain elevation, so simply the applying elevation threshold was good to classify elevated objects.

In the second processing step, the trees had to be separated from buildings, as both were elevated objects. Here again the DSM information was used. It was apparent that Elevation (DSM) texture of the buildings was far smoother than trees, which can be represented by object's standard deviation (Trees - high Elevation Standard Deviation and Building - low Elevation Standard Deviation). So, the thresholding on Standard Deviation was used to separate Trees and Buildings, which were both elevated objects. Nonetheless, some trees were still classified as "Buildings" even after refining the classification using the standard deviation of the DSM layer.

The Green Ratio "green / (red+green+blue)", which measures green component of the color was used for further refinements because, the green layer contains a significant information about the vegetation. But still some areas weren't classified into respective classes. So, the Visible Vegetation Index (VVI) which provides a measure of the amount of vegetation or greenness of an image using only information from the visible spectrum was used as further refinement parameter. The VVI is an alternative procedure that tries to use only information in the visible spectrum by measuring the amount of green in a region using similarity indices. The VVI is given by Equation 1.

$$VVI = \left[\left(1-\frac{|R-R_o|}{|R+R_o|}\right)\left(1-\frac{|G-G_o|}{|G+G_o|}\right)\left(1-\frac{|B-B_o|}{|B+B_o|}\right)\right]^{\frac{1}{w}} \quad (1)$$

Where R, G, and B are the red, green, and blue components of the image, respectively, RGB_o is vector of the reference green color, and w is a weight exponent to adjust the sensitivity of the scale [9]. Then, the classified classes were merged into separate polygons. Again, low area values were assigned to the vegetation class, which were previously classified into the building class. Finally, the non-elevated objects were classified into Ground and Vegetation classes using the Green ratio. The railway line was extracted by using the unclassified ground layer, which was based on the mean DSM. The railway line consists of objects seems to be linear and elongated, having higher length compared to width. Therefore, two indices were used to extract those objects on the railway line such as shape index and length\width ratio. The exact values which were selected for the indices were based on trial and error method.

3. Results and Discussion

The DSM and Orthophoto obtained from the current UAV Photogrammetry processing method are shown in Figure 2 and have a resolution of 3.27 cm/pixel. The RMS errors obtained in X, Y, Z directions when creating the DSM were 3.8452 cm, 5.6003 cm and 8.0532 cm. The overall accuracy of the classified map which is shown in Figure 4 is 90.15%.

The spatial resolution of the DSM obtained from this method was compared with the freely available DEMs. The Space Shuttle Radar Topography Mission (SRTM) and ASTER Global Digital Elevation Model are freely available global DEM data sources. SRTM 1-arc second global DEM has a spatial resolution of about 30 m/pixel covering most of the world with an absolute vertical height accuracy of less than 16 m/pixel. ASTER GDEM has a global resolution of 90 m with a resolution of 30 m/pixel in the United States [10]. The DSM obtained from this method has a very high spatial resolution; i.e. 3.27 cm/pixel, compared to the freely available DEMs by assuming that the terrain information from both DSM and DTM are same for the railway lines. The latest SRTM DEM available for the study area was acquired in 2014 but the DEM can be obtained from this method within a day and it can be obtained on request according to the client's requirement.

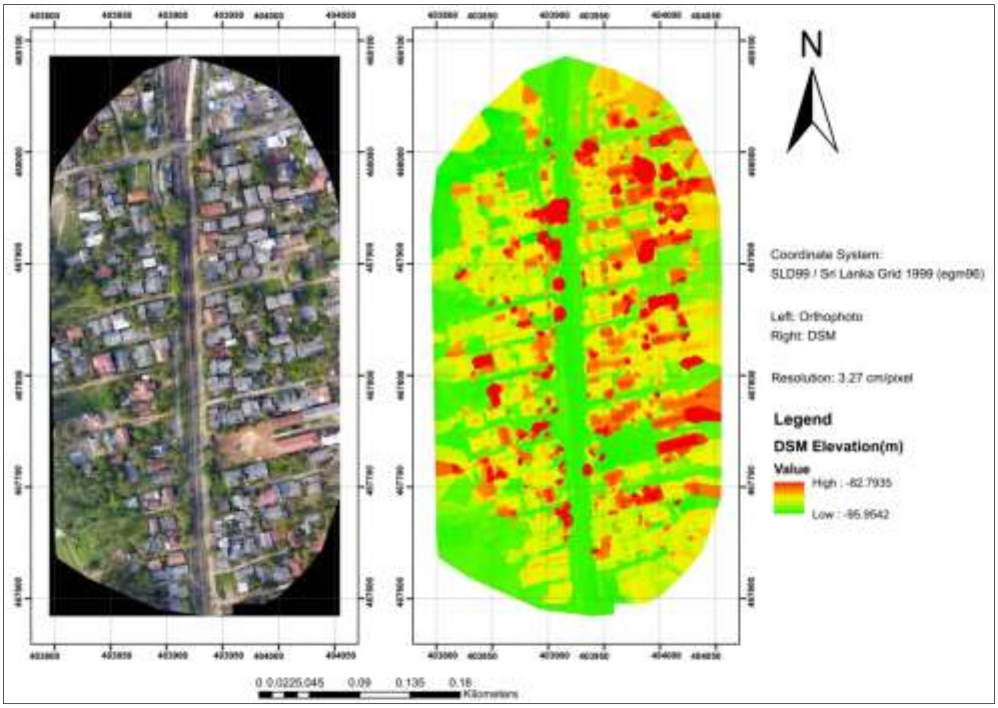

Figure 2 - The DSM and Orthophoto

The RMS error in the Z direction seems to be much higher value compared to other directions. The cause of the error may due to lack of a geoid model for Sri Lanka. Generally, the geoid model is developed from a gravity survey, which is not conducted in Sri Lanka yet.

Therefore, GCPs are calculated using the common ellipsoid of Everest 1830. Also, the GCPs were calculated from CORSnet corrections and when the GCPs are far from the reference stations, the error could be added. The distribution of the check points may affect to the resultant error since they were not well distributed within the study area.

The data can be acquired simply by using the Google Earth for this type of research, but the Google Earth data are not up to date and the resolution is quite low compared to the resolution of developed Orthophoto. Another way of acquiring high resolution images is by using the high resolution satellites such as Worldview, Ikonos, QuickBird and etc. The Worldview-4 images are provided in 25 km^2 footprint with the multispectral resolution of 1.24 m and the panchromatic resolution of 0.31 m. But the developed Orthophoto has the resolution of 3.27 cm/pixel.

The error matrix shown in Table 1 indicates an overall map accuracy of 90.15%. However, supposing the ability to classify buildings was the most interested one, calculate a "producer's accuracy" for this category and it results in a "producer's accuracy" of 94.31%, which is a reasonable value. A calculation of the "user's accuracy reveals a value of 95.41%. In other words, although 94.31% of the building areas have been correctly identified as buildings, only 95.41% of the areas called buildings are actually buildings.

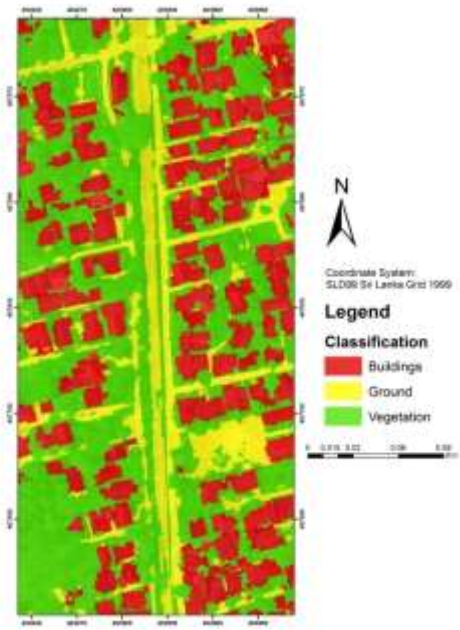

Figure 3 - Land use classification map

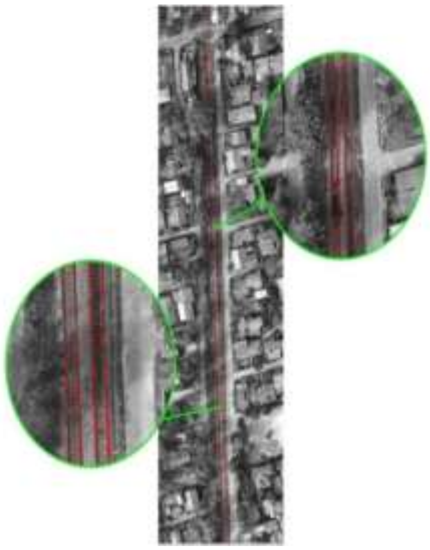

Figure 4 - Railway line extraction

Therefore, although the producer of this map can claim that 94.31% of the time an area that was buildings was identified as such, a user of this map will find that 95.41% of the time will an area he visits that the map says is buildings will actually be buildings. Since, producer accuracy and user accuracy got higher values for each land cover classes and a higher overall accuracy, conclusion can be made that the object oriented classification can be used as an accurate way of classifying land use nearby coastal railway lines.

Table 1 - Error Matrix

OOC Map \ Digitized Map	Ground (1)	Building (2)	Vegetation (3)	Total	User Accuracy %
Ground (1)	**32.00**	0.00	0.42	32.42	**98.72**
Building (2)	1.10	**26.00**	0.15	27.25	**95.41**
Vegetation (3)	6.60	1.57	**32.15**	40.32	**79.74**
Total	39.70	27.57	32.72	100.00	
Producer Accuracy %	**80.61**	**94.31**	**98.26**		**90.15**

The extraction of railway line was based on trial and error method. It could not be obtained as an exact linear object by the object oriented classification method within the limited time period allocated to this research, but through the visual inspection, the railway line extraction can be considered as a successful one. The accuracy assessment process for the railway line extraction was not carried out and it was inspected visually.

"eCognition" and "Pix4D" are commercial software and the unavailability of freely available software for Object Oriented Classification is troublesome. Legal barriers and rules associated with UAVs in Sri Lanka are the main obstacles associated with this approach. With the current advancement of technology and the popularity of UAVs will help to overcome these obstacles in the future.

4. Conclusions

This study presents an overview of using low cost, low altitude (100 m) image data for aerial mapping to use in railway line and nearby land use mapping because the mapping of a railway line by ground based surveying techniques is time consuming and problematic due to the involvement of human errors. Therefore, UAV photogrammetry gives a new approach to the aerial mapping. It proves that low cost drones compared to survey grade drones, also can provide high accurate and high resolution products with very high level of automation which suit many Engineering and GIS applications.

Total accuracy with respect to manual digitizing and visual inspection of the results may validate the approach that have used in this study. Even without Near Infrared band, which is not available in consumer-grade UAVs, this approach successfully maps the vegetation. For the average mapper, mapping the railroad network is a bit more complicated than mapping streets because railway lines are thin linear features having less area which is a significant element to identify railroads compared to roads.

It is prominent that this accuracy is good enough for railway mappers, urban planners for sustainable planning of the urban environment and the railway line information can be used in other engineering application and research.

The Hough transform is recommended to use for the exact feature extraction of railway line. This technique is used in image analysis, computer vision, and digital image processing for the identification of lines in the image and the code can be generated using "MATLAB" software.

Acknowledgement

Authors wish to express their sincere thanks to all academic and non-academic staff of the Department of Earth Resources Engineering of University of Moratuwa, Lieutenant Colonel, L.R.K. Kahandagamage, Center for Research and Development, Ministry of Defence and to the Technical Manager (GNSS Division), Retail IT (PVT) Ltd., Mr. Aruna Weerasinghe, for the assistance given throughout the research work for the successful completion of the research.

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