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Research Article

DEM classifications: opportunities and potential of its applications

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Abstract: DEM is a digital model that provides topographic information. DEM can be made from terrestrial surveys, aerial photography, video, optical, and radar satellites, LIDAR and multidata combination. In general, DEM can be in the form of DSM and DTM. This study aims to explain the classification of DEM based on terrestrial and non-terrestrial, the methods of DEM extraction, vertical accuracy, data formats, and technological trends. The methods of DEM extraction discussed include stereo, interferometry, DEM combination, videogrammetry, and terrestrial data interpolation. In addition, a comparison of vertical accuracy is also carried out with several methods of its extraction. DEM can be used for various applications involving land surface, especially for 3D modeling, spatial planning, geology, topography, and so on. This DEM is used to support the activities of inland waters on Rote islands.

Keywords: *DEM classification, non-terrestrial, terrestrial, Rote islands, vertical accuracy*

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Introduction

The development of survey and mapping technology is characterized by the use of many sensors for various applications. Technologies development affects various height models or 3D models. This height model is also called the Digital Elevation Model (DEM). The term DEM is more commonly used in the United States, Canada, and Western Europe. The term height model is more often used in Russia and Northern Europe. This DEM consists of several types, namely Digital Surface Model (DSM), DEM, Digital Terrain Model (DTM), Digital Ground Model (DGM), Earth Gravitational Model (EGM), Digital Terrain Elevation Model (DTED), and Digital Height Model (DHM), (Li et al., 2005). DEM can be made from optical, video, radar, lidar, and sonar data.

DEM is an important data source for some applications that require surface height information (Amans et al., 2013). DEM is a model of bare earth elevation or surface autocorrelation without vegetation, buildings, and other objects (Petrie and Kennie, 1987). DEM can also be defined as a digital model that provides information on the shape of the earth's surface (topography) in the form of raster data, vectors or other forms of data (Wilson, 2012). Commonly, DEM is 3D Earth projections that can be categorized into two groups: DTM, which are free of trees, buildings, and all types of objects, and DSM, which reflect the surface Earth, including all man-made objects and natural (Martha et al., 2010; Maune and Mayegandhi, 2018). DSM is an elevation model that includes building roofs, trees, and other objects, usually as a canopy model (Li et al., 2005). EGM is a geoid earth model, describing equipotential fields which coincide with mean sea level (Vanicek and Krakiwsky, 1986). DTM is a DEM that has been equipped with rivers, contours, and features that exist in nature (Li et al., 2005).

DSM and DTM are closely related in a variety of applications involving land surface. Soil surfaces play a fundamental role in modulating atmospheric, geomorphic, hydrological and ecological processes that operate on or near the surface of the earth (Montgomery and Dietrich, 1989);

(Sheng et al., 2007). This connection is often so strong that an understanding of the character of the land surface can directly inform our understanding of the nature and magnitude of the processes mentioned earlier (Hutchinson and Gallant, 2000). Applications that exploit this knowledge usually rely on DEM to represent surfaces and a variety of sophisticated and increasingly sophisticated techniques for topographic analysis and visualization.

DEM from optical data uses optical satellite image data, aerial photography, and video. DEM can be made with several methods such as stereo, interferometry, DEM integration, DEM fusion, and others. In optical data, height model extraction uses a stereo model, videogrammetry, and depth cue perceptive. Radar data can use Synthetic Aperture Radar (SAR) satellite image data, Interferometry Synthetic Aperture Radar (IFSAR), LIght Detection and Ranging (LIDAR) data. Height models extraction from radar data uses stereo model, interferometry, and depth cue perceptive. Height models made with sonar can use data from Interferometry Synthetic Aperture Sonar (IFSAS) (Li et al., 2005); (Julzarika, 2015).

This study aimed to explain the classification of DEM based on terrestrial and non-terrestrial, methods of DEM extraction, vertical accuracy, data formats, and technological trends.

Material and Methods

The method in this study discusses the method of DEM extraction, height errors, vertical accuracy, and the research methodology of this paper. Height error is a height anomaly error that occurs due to the peak (spire) and valley (pit) of the eight closest neighbours.

There are several methods of DEM extraction, namely Triangular Irregular Network (TIN), stereo, interferometry, LIDAR, videogrammetry, combining DEM. TIN is a vector-based topology data model that is used to represent terrain. TIN represents the shape of the earth's surface obtained from irregularly distributed sample points and break line features and forms an interconnected triangular network. Each triangle consists of three vertices which have location coordinates x, y, and extension (z) (Nelson et al., 2009).

Stereo models are generally used for optical images. The stereo model considers the relationship between the Base to Height ratio and the backward direction of the observation location on the earth's surface (Trisakti and Julzarika, 2010). The basic concept of stereo DEM extraction is to build a correlation model between the 3D space image system, the sensor, and the 3D space coordinate system (Konecny and Lehmann, 1984). Interferometric Synthetic Aperture Radar (InSAR) is a remote sensing technology that uses radar sensor images from aerial or satellite aircraft (Lusch, 1999). Radar sensors on airplanes and satellites emit radar waves constantly, then the radar waves are recorded after being received back by the sensor due to being reflected by targets on the surface of the earth. (ESA, 2007).

LIDAR is an optical remote sensing technology that measures the properties of scattered light to find distances and / or other information from distant targets. The method for determining the distance to an object or surface is to use laser pulses.Videogrammetry is a technology of measuring coordinates in three-dimensional form from points on an object determined by measurements with the source of two or more video images where the extraction is done from a different perspective.

Combining DEM data is done using two methods, namely DEM integration and DEM fusion. The concept of DEM integration and DEM fusion refers to concepts developed in previous studies (Hoja and D'Angelo, 2010; Hoja et al., 2006). Some modifications were made such as height error correction, making height error maps, adding weight, detection and error removal methods (making voids), and CoKriging interpolation methods performed.

According to (Hoja et al., 2005; Hoja et al., 2006), the best method with higher accuracy for combining DEM is integration, while the fastest method is fusion but less accuracy for DEM combination. DEMNAS is an example of DEM combination using fusion methods. DEMNAS is a national DEM for Indonesia. The DEMNAS is a combination of multi DEM from TerraSAR-X, IFSAR, ALOS PALSAR, and mass points. DEMNAS has a spatial resolution of 8 m. DEM integration method takes longer to process because it requires to reconstruct the DEM by considering there are weights with certain values on the parameters used. Whereas in the methods of DEM fusion uses weight 1 without require to reconstruct the DEM (Julzarika, 2015).

Every DEM extraction has an error (Zhang and Montgomery, 1994). The error is height value anomaly. DEM needs to be corrected for height errors. Height errors are random errors in the form of blunders that occur due to height value anomalies to the eight closest neighbours (Kienzle, 2004). Height errors can be caused by interpolation of wrong contours due to uneven distribution of height points or can be caused by height point values that are not in accordance with the truth (Sefercik and Jacobson, 2006). There are 4 main parameters in checking height errors, namely pit, spire, radius, and depth (Raaflaub and Collins, 2006).

Vertical accuracy standards for DEM generally refer to American Society for Photogrammetry and Remote Sensing (ASPRS) Accuracy Data for Digital Geospatial Data. How to check vertical accuracy tests with 2 steps, namely Root Mean Square Errors (RMSE) and vertical accuracy in 95 % (1.96σ) degree of freedom (ASPRS, 2014); (Gillani and Wolf, 2006). The way to minimize height errors is by height error correction with fill sink, cut terrain, and height error map methods.

The study examines the DEM classification based on the location and type of sensor used. This DEM classification is divided into terrestrial and non terrestrial. This study uses around 31 scientific articles from international journals and proceedings. All DEM discussions on these references are grouped based on the DEM classification: terrestrial and non-terrestrial DEM. Non-terrestrial data can be distinguished into optics, SAR, video, and LIDAR. Terrestrial data includes levelling measurements, theodolites, laser scanners, Global Navigation Satellite System (GNSS), and other terrestrial survey tools.

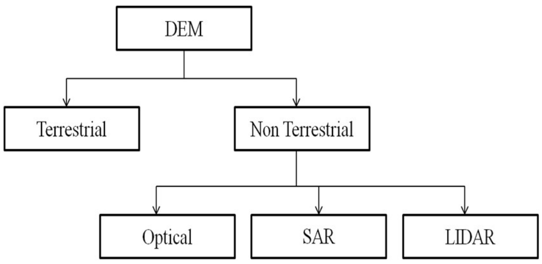

Figure 1. Research flowchart of DEM classification.

The limitations of the topics discussed in this paper in the form of comparison of the DEM classification were reviewed based on terrestrial and non-terrestrial, DEM extraction methods, vertical accuracy, data formats, and technological trends. This DEM classification can be seen in Figure 1. Each DEM classification in Figure 1 will be explained in the results section and discussion.

Results and Discussion

This DEM classification discusses related DEM terrestrial and non-terrestrial. Then each DEM is distinguished by methods. Another thing to do is to make comparisons of DEM terrestrial and non-terrestrial based on spatial resolution, vertical accuracy and horizontal accuracy, scope of acquisition, post-processing needs and forms of processing results. In general, DEM can be distinguished by location and acquisition vehicle. This DEM classification is divided into terrestrial and non-terrestrial. DEM terrestrial is measured by vehicles and sensors that are on the ground or terrestrial. DEM terrestrial has conditions of high accuracy, low precision for large areas, takes a long time to work, and requires high costs. DEM terrestrial can be made using terrestrial measurements such as theodolite, levelling, GNSS, altimeter, total station, laser scanner, and others.

DEM non-terrestrial are divided into optics, video, SAR, and LIDAR. The vehicles use them are airplanes, Unmanned Aerial Vehicle (UAV), satellites, hot air balloons, etc with recording locations in aerial and space. DEM non-terrestrial can also produce DSM/DTM with varied conditions. DEM non-terrestrial can produce low or high vertical accuracy. Non-terrestrial DEM with low vertical accuracy is global DEM. Non-terrestrial DEM with high vertical accuracies such as integration and fusion. In general, DEM non-terrestrial has higher precision compared to DEM terrestrial.

There are several examples of non-terrestrial global DEM that are freely accessible and can be an alternative to various applications. The global models are SRTM C, X SAR, ASTER GDEM, ALOS Prism, and ALOS PALSAR. All DSM/DTM including the global DEM still have a lot of height errors (noise) so it is not optimal in the use for various applications. In general, height errors of DEM non-terrestrial in optical data occur at high frequencies and height errors in SAR data occur at low frequencies.

DEM from SAR can be made at certain vertical accuracy based on the type of band used. Bands that are often used in SAR data are X, C, L, and P. Bands X and C are generally used for making DSM. L and P bands can be used to make DTM. Examples of band X are X SAR, band C is SRTM, band L is ALOS PALSAR, and band P is GeoSAR.

DEM ALOS Palsar can be an alternative fulfilment of needs with a spatial resolution (6-10 m) and vertical accuracy of 2-5 m (Julzarika and Sudarsono, 2009). In SRTM C, X SAR, and ALOS PALSAR data, height errors occur at low frequencies in each pixel.

In SRTM, X SAR, and ALOS PALSAR data, height errors occur at low frequencies in each pixel. Related to DEM ALOS PALSAR and Sentinel, there have been several research references. DEM ALOS PALSAR can be an alternative fulfilment of needs with a spatial resolution (6-10 m) and vertical accuracy of 2-5 m (Julzarika and Sudarsono, 2009). Then (Du et al. 2018) has conducted research related to the correlation of forms of land use. (Xin et al. 2018) have made high-precision DEM based on the image orbit parameters.

The method that they developed will be useful in getting DSM precision. It is different from (Naidoo et al. 2016), they have conducted research related to the use of band L to calculate tree canopies. This will be useful in DSM extraction and its decline into DTM using ALOS PALSAR imagery. In addition, (Polcari et al. 2017) conducted research related to 3D data integration algorithms caused by the phenomenon of rapid deformation. The results of their research can be utilized in the study of data integration.

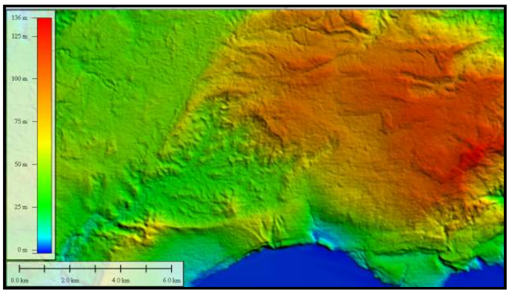

Figure 2. Example DTM integration from IFSAR-ALOS PALSAR-IceSAT/GLAS-SRTM C- X SAR. Area in Rote Islands.

DEM LIDAR can be used for detailed mapping with high accuracy. Accuracy of elevation over canopy, ground height, and vegetation height (VH) originating from space, LIDAR data originating from space in the entire forest area. Dynamic topography of the mapping location can be modeled from various slope angles. Computed altitude metrics from LIDAR data obtained by GLAS sensors on Ice Cloud and Land Elevation Satellite (ICESat) compared to airborne laser scanning (ALS) DEMs (Julzarika, 2015). For the detection of land peaks by smoothing waveforms, it was found that the noise threshold 4 and 4.5 times the standard deviation plus the noise level gave the best performance. For the VH calculation in the slope up to 10◦rain, the as booth 10 bins range reaches $r^2 = 0.58$, while the GLA14 based method reaches r^2 from 0.75 in flat terrain (0–5◦). For this flat area, the best results in calculating VH ($r^2 = 0.91$) were achieved using a new method for detection of canopy peaks and GLA14-based soil elevations. Determination of terrain evaluations was observed to be the best with calculations with GLA14 based parameters. The stronger of the last two peaks is found closest to the ground level.

Examples of DEM extraction

This section discusses the example of DEM based on the extraction method. Integration and fusion methods can be used to combine optical with optical data, optical with SAR data, optical with LIDAR data, SAR with SAR data, SAR with LIDAR data, or a combination of all optical data, SAR, and LIDAR. The interpolation method is used for DTM terrestrial extraction. All measurement data in the form of height points need to be interpolated for making DEM and TIN grids. TIN will produce information that is dense in complex areas and information that is rarely in a homogeneous area. The triangle always has three nodes and usually has three neighbouring triangles, but the triangle on the edge usually has one or two neighbours (Jones, 2013).

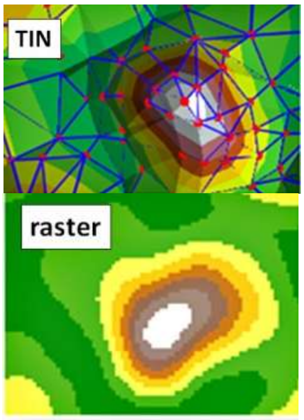

Figure 3. Example of TIN and DEM from terrestrial survey.

In videogrammetry, images can be obtained from two viewpoints that simultaneously display objects or come from sequential images captured by the same video as the display of an object. Videogrammetry extends the technique of close-range photogrammetry and applies it to an image sequence to present or produce a series of three-dimensional models produced using Photogrammetry standard.

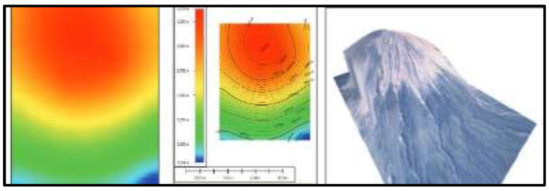

Figure 4. DEM videogrammetry from LAPAN TUBSAT imageries. Area in Mount Semeru. (Julzarika, 2010).

In the stereo method, resection makes a correlation between the image space coordinates system (x, y, z) with the ground space coordinates (X, Y, Z). Resection uses a colinear equation, provided that the central point of sensor, image coordinates and soil coordinates are linear showing the equation of the correlation between the sensor, image, soil and the colinear equation formed. Cholinear equations are used to estimate external orientation parameters (X, Y, Z, ω, φ, κ) which require an input of at least three soil control points or more to get the six coefficients equation.

The forward intersection is used to create an equation that calculates the coordinates of the ground space (X, Y, Z) in the overlap region of two images if it is known the exterior orientation parameters based on the colinear equation. DEM extraction stages consist of (1) mass point collection with image matching; (2) calculation of the coordinates of the ground space (X, Y, Z) for each mass point with a forward intersection technique; (3) the construction of the XYZ coordinate DEM is the mass point by interpolation.

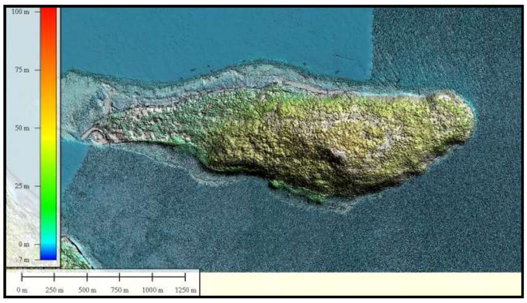

Figure 5. DSM SPOT from satellite. Area in Bali.

In the interferometry method, when the wave is emitted a phase measurement is made. The images obtained from each image element (pixels) will have the two information. Signal intensity can be used to determine the characteristics of objects that reflect the wave, while the wave phase is used to determine whether there has been movement (deformation) on the surface that reflects the wave. (Hoffman and Walter, 2006)

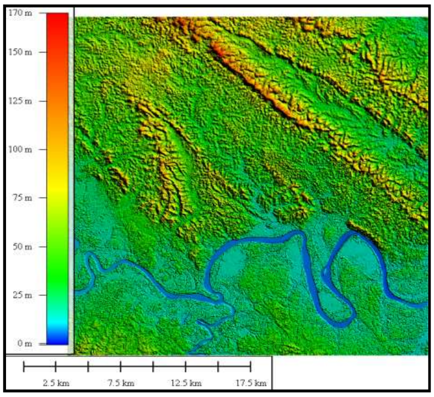

Figure 6. DEM ALOS PALSAR using interferometry. Area in Batang Hari, Jambi.

In interferometry, to obtain the topography of the image must be fulfilled two conditions, namely objects on the surface of the earth that are imaged must be clearly visible or have a high image resolution so that appropriate interpretations and identification can be carried out (ESA, 2007). In addition, the image must have a sufficient three-dimensional position so that the area to be mapped can be known topography (Hengl and Evans, 2009). Both of these can only be fulfilled by the InSAR technique. This is what causes more fields of study to apply InSAR. Interferometry techniques represent an object on the surface of the earth by observing the phase difference of two fluorescent waves originating from an object.

DEM comparison

In general, the DEM comparison from terrestrial, optics, radar and LIDAR can be seen in Table 1. DEM terrestrial in the form of DTM field surveys, GNSS, digitizing tables, digitizing on screen, and topo scan maps. DTM field surveys have varying spatial resolutions, generally <5 m. The accuracy of DEM terrestrial and GNSS is very high for horizontal and vertical. The area of coverage varies, generally not broad. A little post-processing needs DTM from digitizing tables, digitizing on screen, topo scan maps having spatial resolution depending on scale and contour interval. Vertical and horizontal accuracy at the middle level. The coverage is also not extensive, it still needs further processing.

Non terrrestris DEM in the form of aerial, LIDAR, and satellite images. Ortho photos have a spatial resolution of <1 m. Vertical and horizontal accuracy is very high but has high post-processing needs. The processing results are still in the form of DSM. The LIDAR DEM has a spatial resolution of 1-3 m with a vertical accuracy of 0.15-1 m and horizontal accuracy of 1 m. Coverage of around 30-50 ha with high post-processing needs. The processing results are in the form of DSM and DTM. The DEM IFSAR has a spatial resolution of 2.5-5 m with a vertical accuracy of 2 m and horizontal accuracy of 2.5-10 m. Its coverage depends on the acquisition. Post-processing needs are still high. The processing results are in the form of DSM and DTM.

DEM non-terrestrial from satellite has several criteria. DEM from satellites has various spatial resolutions, ranging from <1 m to > 1 km. In Table 1 it can be concluded that the accuracy of DEM terrestrial and DEM non-terrestrial has a particular uniqueness. Examples of such global DEM are SRTM C, X SAR, ASTER GDEM, ALOS Prism, and ALOS PALSAR. All DSM/DTM including global DEM still have a lot of height error that is not optimal in the use of various applications.

Table 1. DEM Comparison of terrestrial and non terrestrial.

DEM Classification	Source Data	Accuracy	Spatial resolution	Post processing needed	DSM/DTM
Terrestrial	Terrestrial survey	Very high vertical and horizontal	< 5 m ; > 1:5000	Low	DTM
Terrestrial	Topo map scan	Medium vertical and horizontal	Depends on map scale; 1:5000-1:50.000	High	DTM
Terrestrial	On screen digitation	Medium vertical and horizontal	Depends on map scale; 1:5000-1:50.000	Medium	DTM
Terrestrial	Table digitation	Medium vertical and horizontal	Depends on map scale; 1:5000-1:50.000	Medium	DTM
Terrestrial	GNSS	Medium vertical and horizontal	<5 m; 1:1000-1:10.000	Low	DSM/ DTM
Terrestrial	Ortho photography	Very high vertical and horizontal	<1 m; 1:1000-1:10.000	High	DSM
Non terrestrial	LIDAR	0.15–1 m vertical, 1 m horizontal	1-3 m; 1:500-1:5000	High	DSM & DTM
Non terrestrial	IFSAR	2 m vertical, 2.5–10 m horizontal	2,5-5 m; 1:5000-1:25.000	High	DSM & DTM
Non terrestrial	SRTM C	16 m vertical, 20 m horizontal	3 arc second; 1:50.000-1:100.000	High	DSM
Non terrestrial	X SAR	16 m vertical, 6 m horizontal	1 arc second; 1:25.000-1:50.000	High	DSM
Non terrestrial	DEMNAS	4 m vertical	8 m; 1:25.000-1:50.000	High	DSM
Non terrestrial	ALOS PALSAR	3-5 m vertical	6-12 m; 1:10.000-1:25.000	Medium	DSM
Non terrestrial	ASTER GDEM	7–50 m vertical, 7–50 m horizontal	30 m; 1:50.000-1:100.000	Medium	DSM
Non terrestrial	SPOT	10 m vertical, 15 m horizontal	5-30 m; 1:25.000-1:100.000	Medium	DSM

Research on combining DEM has been carried out by (Honikel, 1998; Keydel et al., 2000; Yastikh, 2006; Schneider et al., 2008; Hoja et al., 2006; Trisakti and Julzarika, 2010, Hoja and D'angelo, 2010). Vertical accuracy of X SAR is 3-5 m (Gech, 2005) and 5-6 m (Yastikh, 2006). The vertical accuracy of SRTM C is 9.6 m according to (Yastikh, 2006). Vertical Accuracy ALOS Prism 2-5 m (Bignone and Umakawa, 2008); <6.5 m (JAXA, 2006). Vertical accuracy of ALOS PALSAR (2-3 m (Julzarika and Sudarsono, 2009); 4 m (Schneiger et al., 2008). SRTM C has global vertical accuracy in 10-16 m. If height error correction is made, the vertical accuracy can be optimized to 5-8 m. The integration of SRTM C with ALOS Palsar and X SAR is able to increase vertical accuracy up to 1-5 m (Trisakti and Julzarika, 2010). Even in lowland areas such as Merauke, vertical accuracy of ~80 cm is obtained (Julzarika and Dewi, 2018). In addition, other spaceborne sensors are also installed, namely X SAR with a spatial resolution (1 arc second=25 m). X SAR has a spatial resolution of 3-5 m for the Indonesian region (DLR, 2010). X SAR has 25 m in spatial resolution. It has an accuracy of 3 m but does not cover all regions of Indonesia (Keydel et al., 2000), besides DSM IFSAR data often has errors caused by layover, shadow and atmospheric effects (temporal decorrelation) (Karkee et al., 2006).

Each DEM has differences in certain applications based on vertical accuracy and the form of processing results in the form of DTM or DSM. The application for using DEM is determined based on a certain scale that is adjusted to the vertical accuracy of the DEM. This vertical accuracy is influenced by the detail and difference between DEM and measurement of height points in the ground or terrain. The smaller the difference in height, the higher the vertical accuracy. High vertical accuracy can be used for large scale mapping.

This vertical accuracy is generally influenced by geoid undulations and height errors. This geoid undulation depends on the height reference system in each country. In Indonesia, generally using global geoids such as EGM96, EGM 2008. In addition, there are also those who use Indonesia's dynamic height system, SRGI 2013. Global DEMs such as SRTM and X SAR still use EGM96. If it uses EGM2008 on height reference field correction, it will increase the vertical accuracy.

The vertical accuracy of ASTER GDEM is also not good due to the creation of high stereo matching models automatically from ASTER images with the determination of the number of tie points in large quantities. This automatic stereo matching does not guarantee that the correlation between data becomes more optimal. The recommended DEM combinations for use in various applications are SRTM C and ALOS PALSAR.

Combining DEM boundaries is also needed especially in the analysis of contour and high profile patterns (Mukti et al., 2018). Analysis of contour patterns and altitude profiles requires a continuous DEM, there is no height value piece that is in this seamless DEM. Checking the contour pattern and altitude profile is done to see if the mosaic results are smooth and seamless. Checking contour patterns and altitude profiles is carried out on each mosaic result, both weightless mosaic and mosaic with weight. Checking the height profile in the sample area illustrates smooth and seamless results in the connection area of the results, the mosaic results are smooth and seamless without weight at the junction area, while the mosaic with weights shows good results. Mosaic with weight can produce smooth and seamless data in the second connection area of the data. At the weightless mosaic results, there are still some areas that are not seamless and smooth in the connection area between the two data.

Technology trends

At present, the development of DEM is more to rapid production and its vertical accuracy. DEM LIDAR is currently growing rapidly. Now, LIDAR is not only used with aircraft and terrestrial aircraft but has also been developed into UAVs and satellites.

Utilization of LIDAR satellites has reduced the cost and time of making DEM. DEM SAR also develops with certain types of bands. This is due to DSM, DTM, vegetation height, deformation especially for areas with lot of clouds. DEM SAR is more developed using bands X, C, and L.

DEM Optical is less developed. Its development is towards the spatial resolution of the image used for DEM extraction in stereo. The DEM of the video is still underdeveloped. Videos are more widely used for 3D modeling. Combining DEM is one of topography mapping in inland waters, geology, and other geobiophysical applications. This DEM is used to support the Indonesian activities of inland waters on Rote islands. DEM LIDAR and DEM SAR are also useful for inland water, geology, and geobiophysical applications.

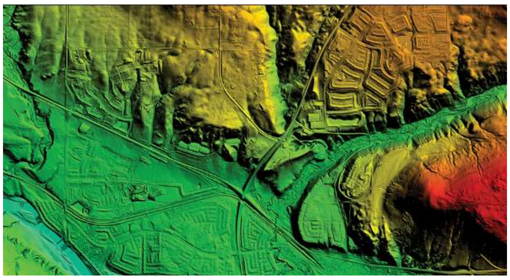

Figure 7. Example of DEM LIDAR.

Conclusion

This DEM classification is divided into terrestrial and non-terrestrial. Non-terrestrial data can be distinguished by optics, SAR, video, and LIDAR. Terrestrial data includes levelling measurements, theodolites, laser scanners, GNSS, and other terrestrial survey tools. Each DEM has differences in certain applications based on vertical accuracy and the form of processing results in the form of DTM or DSM. The application for using DEM is determined based on a certain scale that is adjusted to the vertical accuracy of the DEM.

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