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Visualization of a Digital Elevation Model using Advanced Image Processing

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Abstract*: Advancements in the field of satellite technologies have made it available to us to acquire the latest imagery, but due to a lack of visualization techniques it becomes very difficult for a person to ascertain the actual situation from a remote place. In this paper we have discussed an attempt to better ascertain satellite imagery with the help of rasters and topographical tools.
Keywords: Advanced Image Processing, DEM, DSM, DTM, Satellite Image Processing

I. INTRODUCTION

The process of Image processing is that of transforming an image into a digital form also performing certain operations to extract some useful information from it. The image processing system usually treats all images as 2D signals when applying certain predetermined signal processing methods.

There are five main types of image processing:

1) *Visualization* **-** Find objects that are not visible in the image
2) *Recognition* **-** Distinguish or detect objects in the image
3) *Sharpening and Restoration* **-** Create an enhanced image from the original image
4) *Pattern Recognition* **-** Measure the various patterns around the objects in the image
5) *Retrieval* **-** Browse and search images from a large database of digital images that are similar to the original image

A. Evolution of Advanced Image Processing

The growth of deep learning technologies has led to the rapid acceleration of computer vision in open source projects, which has only increased the need for image processing tools. The demand for professionals with key skills in deep learning technologies is growing at a rapid pace every year.

The existing advanced terrain related image processing systems are classified into three types:

1) *Digital Elevation Model (DEM):* A Digital Elevation Model (DEM) is a digital representation of the bare ground topographic surface or terrain. DEMs are used often in geographic information systems, and are the most common basis for digitally-produced relief maps. A digital elevation model is a bare-earth raster grid referenced to a vertical datum. When you filter out non-ground points such as bridges and roads, you get a smooth digital elevation model. The built (power lines, buildings, and towers) and natural (trees and other types of vegetation) aren't included in a DEM.
2) *Digital Surface Model (DSM):* In a LiDAR system (5,11,12,15,18), pulses of light travel to the ground. When the pulse of light bounces off its target and returns to the sensor, it gives the range (a variable distance) to the Earth. Hence, how this system earned its name Light Detection and Ranging. In the end, LiDAR delivers a massive point cloud with elevation values. But height can come from the top of buildings, tree canopy, powerlines, and other features. A DSM captures the natural and built features on the Earth's surface. A DSM is useful in 3D modeling for telecommunications, urban planning, and aviation.
3) *Digital Terrain Model (DTM):* In some countries, a DTM is actually synonymous with a DEM. This means that a DTM is simply an elevation surface representing the bare earth referenced to a common vertical datum. In the United States and other countries, a DTM has a slightly different meaning. A DTM is a vector data set composed of regularly spaced points and natural features such as ridges and breaklines. A DTM augments a DEM by including linear features of the bare-earth terrain. Digital Terrain Model or DTM in short, is one of the three advanced image processing models that helps enable a better understanding of satellite or remotely sensed images. DTM is a 3-Dimensional model near-replica of the bare earth that consists of all the topographic features such as the depth, height, length and so on. Over the years, many researchers and scientists have with the help of Digital Surface and Digital Elevation Models generated techniques to help build the Digital Terrain Model, which is by far the most successful feat in the area of research.

B. Organizational Structure

The outline of the rest of the paper is as follows: In section II we have presented a literature review of text summarization. Section III describes our proposed idea/system of digital image processing from satellite images. In section IV, the result of our proposed system is discussed which involves evaluation as well as performance measures of our system. Section V concludes our study.

II. LITERATURE SURVEY

There has been a lot of development in the field of Image processing in the past 10 years. With every advancement comes a new technique with a more optimized approach. Some of these techniques are mentioned below

A. Use Of Satellite Imagery For Dem Extraction, Lanscape Modeling And Gis Applications [1]

This paper describes a workflow for the DEM extraction from unrectified satellite stereo scenes, its visualization and integration in the GIS environment. The results obtained using a stereo scene acquired by EOS-AM1/ASTER (1,6) over Switzerland are presented and commented on. The images are oriented with a rigorous photogrammetric model for CCD linear array sensors developed at IGP (ETH Zurich). The model estimates the sensor internal and external orientation with least squares adjustment, using a suitable number of ground control points. For the DEM generation, the points are automatically extracted in the images at sub-pixel accuracy with a least squares matching algorithm and their 3D coordinates are then calculated with forward intersection using the external and internal parameters estimated during the image orientation. After the surface generation, the terrain model is used for further investigations within a commercial GIS package

B. Analysis the Accuracy of Digital Elevation Model (DEM) for Flood Modelling on Lowland Area [2]

The research about the application of Digital Elevation Model (DEM) in hydrology was increased where this kind of model will identify the elevation for required areas. University of Tun Hussein Onn Malaysia is one of the lowland areas which faced flood problems in 2006. Therefore, this area was chosen in order to produce DEM which focussed on University Health Centre (PKU) and drainage area around Civil and Environment Faculty (FKAAS). Unmanned Aerial Vehicle used to collect aerial photos data then undergoes a process of generating DEM according to three types of accuracy and quality from Agisoft PhotoScan software. The higher the level of accuracy and quality of DEM produced, the longer time taken to generate a DEM. The reading of the errors created while producing the DEM shows almost 0.01 different. Therefore, it has been identified that there are some important parameters which influence the accuracy of DEM.

C. Estimating Coastal Digital Elevation Model Uncertainty [3]

A methodology to derive uncertainty surfaces that estimate coastal DEM vertical errors at the DEM cell–level.The estimated uncertainty can be propagated into the modeling of coastal processes that utilize DEMs by deriving numerous plausible DEM realizations within the uncertainty bounds. The numerous DEMs realizations can then produce an ensemble of coastal modeling results, and in turn, better-informed coastal management decisions.

D. Digital Elevation Model Quality Assessment Methods: A Critical Review [4]

Reviews the main quality assessment methods for two approaches, called external and internal quality assessment. The errors and artifacts are described. The methods to detect and quantify them are reviewed and discussed. Different product levels are considered, i.e., from point cloud to grid surface model and to derived topographic features, as well as the case of global DEMs. The issue of DEM quality is considered from the producer and user perspectives.

E. Implications of Using Global Digital Elevation Models for Flood Risk Analysis in Cities [5]

Comparison of flood extents, hydrographs, depths, and impacts between hydrodynamic simulations, using five spaceborne GDEM products and an airborne LIDAR (5,11,12,15,18) product.

Variability in the accuracy of models using different GDEMs. The corrections applied to the MERIT DEM had a positive effect on flood extent accuracy, relative to other GDEMs.TanDEM-Xprovided the best performance for river channel discharge, making it a more appropriate choice for appli-cations where timing, channel level and flow are important.However, all resulted in substantially higher impacts than the DEM produced from aerial LIDAR survey—with GDEMs estimating the number of build-ings flooded to be 2 to 3 times higher.

F. On the topographic entity-oriented digital elevation model construction method for urban area land surface [6]

First, landforms with common features are abstracted into a certain type of topographic entity based on their morphologies and semantics. For each type of topographic entity, a DEM was constructed independently based on the available elevation information and other information about the semantics and spatial relationships. Second, individual DEMs were merged into a complete DEM following certain rules. A 1 km2 area located in the suburb of Nanjing, Jiangsu Province, China, was selected as the experimental area.

G. Digital surface model based on aerial image stereo pairs for 3D building [7]

The construction of a digital surface model based on aerial image stereo pairs using a matching method and the use of this DSM for 3D city planning. Used aerial photographs with high accuracy (1/4000) covering the study area acquired in 2007 and additional cartographic data from Fez. 3D land use zoning allowed building volumes, usage, and density. They are the main tools defining the image of a city and bring into focus the model of best practice of the rehabilitation and conservation of the historic Medina.

H. DSM Generation from Single and Cross-Sensor Multi-View Satellite Images Using the New Agisoft Metashape [8]

Investigated two different case studies to evaluate the accuracy of the generated DSMs.The first dataset consists of a triplet of Pléiades images acquired over the area of Trento and the Adige valley,which is characterized by a great variety in terms of geomorphology, land uses an land covers. The second consists of a triplet composed of a WorldView-3 stereo pair and a GeoEye-1 image, acquired over the city of Matera (Southern Italy), one of the oldest settlements in the world.

I. Structure-from-Motion-Derived Digital Surface Models from Historical Aerial Photographs: A New 3D Application for Coastal Dune Monitoring [9]

The application of the modern SfM methodology to the analysis of historical aerial (vertical) photography is a novel (and reliable) new approach that can be used to better quantify coastal dune volume changes. DSMs derived from suitable historical aerial photographs, therefore, represent dependable sources of 3D data that can be used to better analyze long-term geomorphic changes in coastal dune areas that have undergone retreat.

J. Densification Of Dtm Grid Data Using Single Satellite Imagery [10]

The paper describes that Digital Terrain Models (DTMs) are simply regular grids of elevation measurements over the land surface. DTMs are mainly produced by applying the technique of stereo measurements on images from photogrammetry and remote sensing. Shape from Shading (SFS) is one of the methods to derive the geometric information about the objects from the analysis of the monocular images.

K. Assessment of Cartosat-1 and WorldView-2 stereo imagery in combination with a LiDAR-DTM for timber volume estimation in a highly structured forest in Germany [11]

The paper touches on the Cost-efficient monitoring systems are required to accomplish the increasing demand for accurate information about the status and the production potential of forests. In general, terrestrial forest inventories with different geographical scope are carried out to collect quantitative data about forests. According to several authors, the utilization of remote sensing techniques can improve the efficiency and accur- acy of forest inventories. Combining remote sensing data and field measurements facilitates the generation of detailed maps, showing the spatial distribution of forest attributes which cannot be achieved with in situ data alone.

L. Advanced Dtm Generation From Very High Resolution Satellite Stereo Images [12]

This work proposes a simple filtering approach that can be applied to digital surface models in order to extract digital terrain models. It represents an evolution of an existing DTM generation method and includes distinct advancement through the integration of multi-directional processing as well as slope dependent filtering, thus denoted “MSD filtering”. The DTM generation workflow is fully automatic and requires no user interaction. Exemplary results are presented for a DSM generated from a Pléiades tri-stereo image data set. Qualitative and quantitative evaluations with respect to highly accurate reference LiDAR data confirm the effectiveness of the proposed algorithm.

M. Classification and Segmentation of Satellite Orthoimagery Using Convolutional Neural Networks [13]

The paper tells us that a convolutional neural network (CNN) can be applied to multispectral orthoimagery and a digital surface model of a small city for a full, fast and accurate per-pixel classification. The investigated land area is fully manually labeled into five categories (vegetation, roads, buildings and water), and the classification accuracy is compared to other per-Pixel classification works on other land areas that have a similar choice of categories.

N. Extraction of DTM from satellite images using neural networks [14]

This thesis presents a way to generate a Digital Terrain Model from a Dig-ital Surface Model and multi spectral images including the Near Infrared. This in turn is used to filter the dsm to a dtm.

Additionally, the addition of the nir color band resulted in an improvement of the accuracy of the classifier.

Using the classifier, a dtm was easily extracted without removing natural edges or height variations in the forests and cities.

O. Digital Terrain Models [15]

A Digital Terrain Model (DTM) approximates a part or the whole of the continuous terrain surface by a set of discrete points with unique height values over 2D points. Heights are in approximation vertical distances between terrain points and some reference surface (e.g., mean sea level, geoid and ellipsoid) or geodetic datum. DTMs are therefore “2.5D” rather than truly 3D models of the terrain (Weibel and Heller, 1991). These models are rather DSM than DTM unless vegetation and building heights are removed. The concept of DTM is not only limited to Earth’s visible terrain surface

.

P. DTM Generation From Aerial Photo And Worldview-3 Images By Using Different DSM Filtering Method [16]

The goal of this study is to analyze the suitability of the filtering method towards the generation of Digital Terrain Model (DTM) from the Digital Surface Model (DSM). Furthermore, three different DSM filtering methods are used which are Elevation Threshold with Expand Window (ETEW), 2D Morphological Square (Morph 2D Filter), and Adaptive TIN (A-Tin). Also, the visual interpretation from their correspondent images is used to evaluate the quality of the filtering process. The missing of the non-ground point due to the filtering process than filling by implementation the same interpolation algorithm. The ETEW and A-Tin filter algorithms are suitable for residential areas.

Q. Filtering DSM extraction from Worldview-3 images to DTM using open source software [17]

The paper talks about the Indonesian maps scale and the efforts to accelerate large scale map production are required. One of the challenges is producing DEM. DEM data extraction from high resolution optical satellite imagery is an efficient choice for the production of large area DEM.

This study uses Worldview 3 stereo ready images for DSM Extraction.Although the DSM data have a high resolution 30cm x 30cm the DEM extraction techniques from optical images produce DSM data instead of DTM. While topographic maps generally use DTM data instead of DSM. So, the goal of this study is to use an appropriate procedures method in OpenSource software towards the generation of BareEarth data by filtering DSM. The OS software is SAGA-GIS that can be used for any point cloud data.Final product is a high resolution DTM which has 30cm x 30cm grid spacing .

R. An Efficient Multi-stage Object-Based Classification to Extract Urban Building Footprints from HR Satellite Images [18]

Urban building information can be effectively extracted by applying object-based image segmentation and multi-stage thresholding on High Resolution remote sensing satellite images. This study provides the results obtained using this method on the images of Indian remote sensing satellite, CARTOSAT-2S launched by the Indian Space Research Organization. In this study, a method is developed to extract urban building footprints from the HR remote sensing satellite images. The first step of the process consists of generating a highly dense per pixel Digital Surface Model by using a semi global matching algorithm on HR satellite stereo images and applying robust ground filtering to generate Digital Terrain Model. In the second step, a multi-stage object-based approach is adopted to extract building bases using the PAN sharpened image, normalized Digital Surface Model derived from DSM and DTM, and Normalized Difference Vegetation Index. The results are compared with the manual method of drawing building footprints by cartographers. The results are found to be in a match with the method using the high resolution Airborne LiDAR DSM by providing a solution for large areas, low cost and low time.

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S. Comparison Assessment Of Digital 3d Models Obtained By Drone-Based Lidar And Drone Imagery [19]

The purpose of the study is to assess the potential of drone airborne LiDAR technology in Morocco in comparison with drone photogrammetry.The study was motivated by the following reasons: Limited number of studies in Morocco on drone-based LiDAR technology applications, Lack of study on the parameters that influence the quality of drone-based LiDAR surveys as well as on the evaluation of the accuracy of derived products.In this study, the evaluation of LiDAR technology was carried out by an analysis of the geometric accuracy of the 3D products generated: Digital Terrain Model, Digital Surface Model and Digital Canopy Model.

They conducted a comparison with the products generated by drone photogrammetry and GNSS surveys.Several tests were carried out to analyze the parameters that influence the mission results namely height, overlap, drone speed and laser pulse frequency. The processing phase was carried out. It includes: the cleaning, the consolidation then the classification of point clouds and the generation of the various digital models.

III. PROPOSED SYSTEM

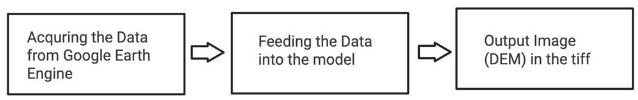

Fig 1: Block diagram

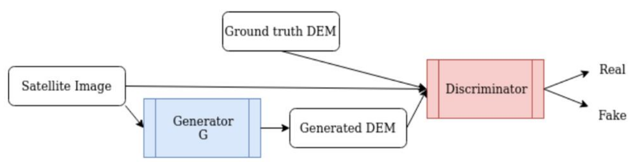

Fig 2: Algorithm Flow Chart

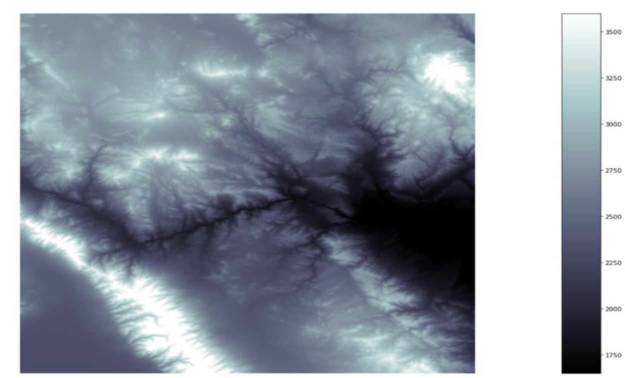

Fig 3: Enhanced DEM

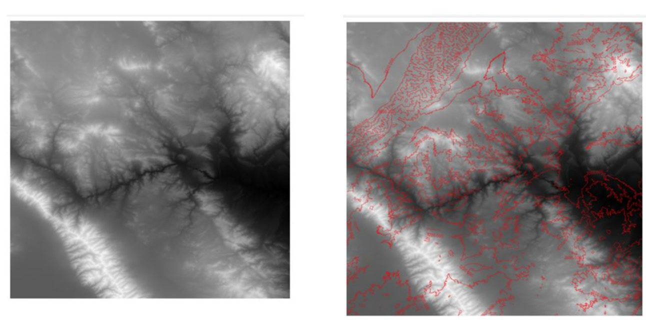

Fig 4: Modified DEM showing the contour lines

Rasters are basically georeferenced images. That is, in addition to the numeric array that contains the image values that every image has, a raster also has metadata specifying the rectangular extent that the image corresponds to in a particular spatial Coordinate Reference System. Rasters are stored in special formats, such as GeoTIFF (.tif) or Erdas Imagine Image (.img).
The tool that is used to convert a raster to a final output dem is called Topographic Aspect.
With the Topographic Aspect tool, you can

1) Find all north-facing slopes on a mountain as part of a search for the best slopes for ski runs.
2) Calculate the solar illumination for each location in a region as part of a study to determine the diversity of life at each site.
3) Find all southerly slopes in a mountainous region to identify locations where the snow is likely to melt first as part of a study to identify those residential locations likely to be hit by runoff first.
4) Identify areas of flat land to find an area for a plane to land in an emergency.

Topographic Aspect and it is calculated in two ways:

a) Planar
b) Geodesic

With the planar method, the computation will be performed on a projected flat plane using a 2D Cartesian coordinate system. With the geodesic method, the calculation will be performed in a 3D Cartesian coordinate system by considering the shape of earth as an ellipsoid.
Both planar and geodesic computations are performed using a 3 by 3 cell neighborhood (moving window). The computation also requires at least seven cells neighboring the processing cell to have valid values. If there are fewer than seven valid cells, the calculation will not be performed, and the output at that processing cell will be NoData. The cells in the outermost rows and columns of the output raster will be NoData.

A. Planar Aspect Algorithm

A moving 3 by 3 window visits each cell in the input raster, and for each cell in the center of the window, an aspect value is calculated using an algorithm that incorporates the values of the cell's eight neighbors.
The rate of change in the x direction for cell e is calculated with the following algorithm:

$$[dz/dx] = ((c + 2f + i) * 4/wght1 - (a + 2d + g) * 4/wght2) / 8$$

where:
$wght1$ and $wght2$ are the horizontal weighted counts of valid cells.

For instance:
if c, f, and i all have valid values, $wght1 = (1 + 2 * 1 + 1) = 4$.
if i is NoData, $wght1$ = (1+2*1+0) = 3.
if f is NoData, $wght1$ = (1+2*0+1) = 2.
Similar logic applies to $wght2$, except the eighbor locations are a, d, and g.
The rate of change in the y direction for cell e is calculated with the following algorithm:
where:
$wght3$ and $wght4$ are the same concept as in the $[dz/dx]$ computation.
Taking the rate of change in both the x and y direction for cell e, aspect is calculated using the following:

$$aspect = 57.29578 * atan2([dz/dy] - [dz/dx])$$

The aspect value is then converted to compass direction values (0-360 degrees), according to the following rule:

```
if aspect < 0
   cell = 90.0 - aspect>
 else if aspect > 90.0
   cell = 360.0 - aspect + 90.0
 else
   cell = 90.0 - aspect
```

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B. Geodesic Method

The geodesic method measures surface aspect in a geocentric 3D coordinate system—also called the Earth Centered, Earth Fixed (ECEF) coordinate system—by considering the shape of the earth as an ellipsoid. It will use the z-units of the input raster if they are defined in the spatial reference. If the spatial reference of the input does not define the z-units, you will need to do so with the z-unit parameter.

The ECEF coordinate system is a 3D right-handed Cartesian coordinate system with the center of the earth as the origin, where any location is represented by X, Y and Z coordinates.

The geodesic computation uses an X, Y, Z coordinate that is calculated based on its geodetic coordinates (latitude φ, longitude λ, height h). If the coordinate system of the input surface raster is a projected coordinate system (PCS), the raster is first re-projected to a geographical coordinate system (GCS) where each location has a geodetic coordinate, and then transformed to the ECEF coordinate system.

To transform to ECEF coordinates from a geodetic coordinate (latitude φ, longitude λ, height h), use the following formulas:

$$X = (N(\varphi) + h) cos\varphi cos\lambda$$
$$Y = (N(\varphi) + h) cos\varphi sin\lambda$$
$$Z = (b2/a2 * N(\varphi) + h) sin\varphi$$

where:
N(φ) = a2/ √(a2cosφ2+b2sinφ2)
φ = latitude
λ = longitude
h = ellipsoid height
a = major axis of the ellipsoid
b = minor axis of the ellipsoid

The ellipsoid height h is in meters in the above formulas. If your input raster's z-unit is specified in any other unit, it will be internally transformed to meter.

The geodesic aspect at a location is the direction of the downslope surface with respect to north, on a plane that is parallel to the ellipsoid surface. To calculate the aspect at each location, a 3 by 3 cell neighborhood plane is fitted around each processing cell using the Least Squares Method (LSM).

Here, the plane is represented as $z = Ax + By + C$. For each cell center, dzi is the difference between the actual z-value and the fitted z-value.

The plane is best fitted when $\sum 9i = 1dzi2$ is minimized.

After the plane is fitted, a surface normal is calculated at the cell location.

Since the tangent plane of the ellipsoid surface is considered the reference plane, the surface normal is perpendicularly projected onto the plane. Finally, the geodesic aspect is calculated by measuring the angle α in the clockwise direction between the north and the perpendicular projection of the surface normal (see the illustration above).

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IV. RESULTS

Now that we have arrays, we can analyze and create other DEM-derived visualizations, including Slope, aspect, and curvature. Before we do that, we can also visualize the DEM like this.

We can also create DEM slope, aspect, and curvature attributes.

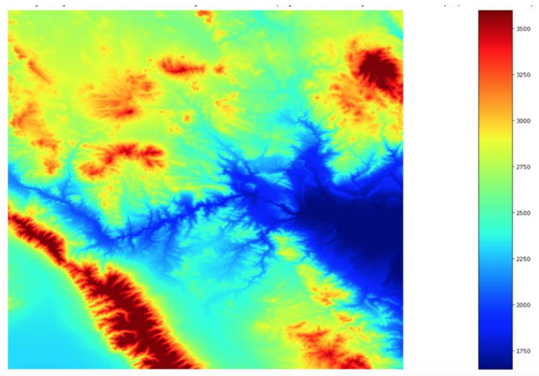

Fig 5: Modified DEM showing the depressions

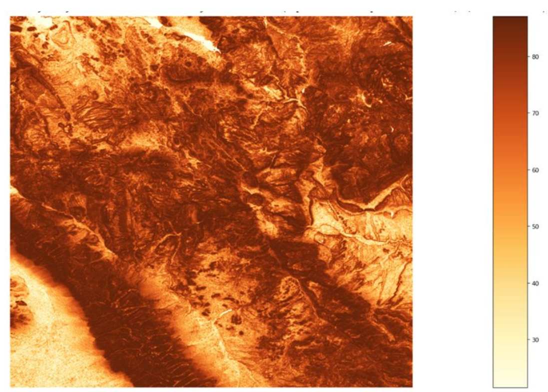

Fig 6: Modified DEM showing the slope

V. CONCLUSION

The Image Visualization shown above shows the different ways we can modify and show the same image such as depressions, slope and contour lines which provides and shows important and crucial information about the image and thereby helps the person understand the actual ground truth better rather than looking at a flat image.

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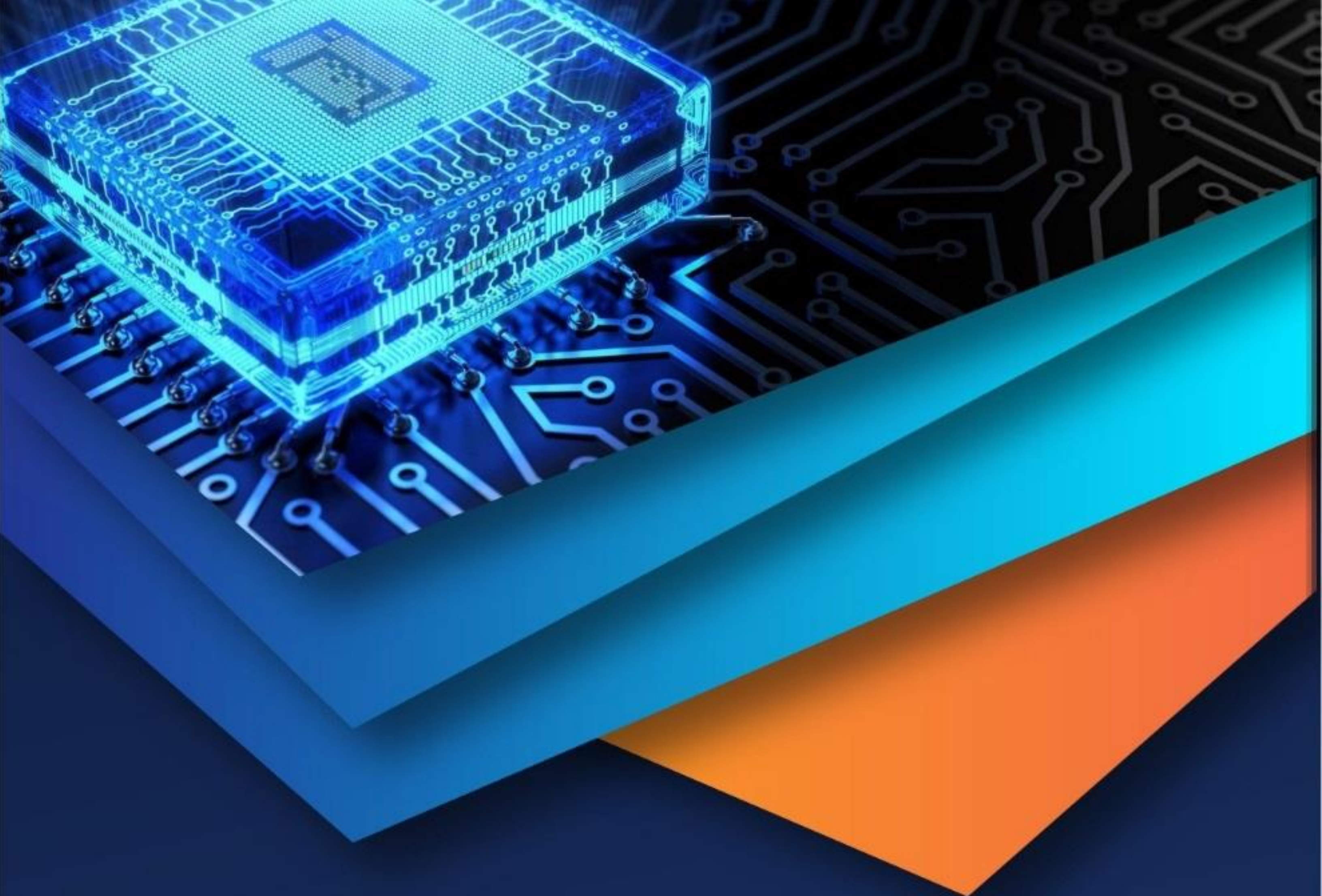

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7.429

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