

Basin Division Method for TIN-based DEM with Face-Node-Edge Flow Mode

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Abstract. The basin serving as a basic unit is of great importance for flood inundation and other hydrological fields. Most existing basin division methods have been proposed for a raster-based DEM and used in some hydrological software, such as the ArcHydro tool and the RiverTool. Unfortunately, raster has some limitations when compared to TIN; specifically, it cannot depict real ground water flow accurately and reasonably. Referring to the natural law of gravity, which dictates water flowing from high to low areas, we present a Face-Node-Edge (FNE) flow mode for TIN-based DEM. The FNE flow mode assumes the water on each triangle facet flows to its lowest node initially. The water on the lowest node then flows along the steepest edge to its neighbour node; the flow continues until the neighbour nodes' elevations are higher than its own. Meanwhile, upstream triangles pass their flow flags to the downstream triangles along the flow path. After that we can generate basins according to the flags. The case studies demonstrate that the proposed FNE flow mode and basin division method for TIN-based DEM are correct, which can provide more reasonable basin division results than raster, e.g., the ArcHydro tool.

1. Introduction

The Digital Elevation Model (DEM) has been successfully utilised in digital hydrology for decades. A number of related algorithms have been developed, e.g., pit extraction, flow path trace, and basin division. Flow mode is the basic principle for depicting the hydrological elements. However, tremendous research has been put forward for a raster-based DEM because of its simple data structure and its easy, practical algorithms. Bänninger [1] summarised the common raster approaches as three types: (a) a single flow direction based on the altitude differences between cells, (b) a random flow direction with a probability distribution proportional to the altitude differences between the center and neighbour cells, (c) multiple flow directions weighted according to the slopes to the adjacent cells. Some basin or catchment division research has been introduced based on the above flow routing modes, such as works by Marks [2], Martz and Garbrecht [3]. These methods have already been embedded in some hydrological software, including ArcHydro Tool and RiverTool. However, the disadvantages of a raster-based DEM influencing the hydrology elements are evident, such as a constrained four or eight flow direction [2,4] Z-shape flow routing[3]. Compared with raster, the advantages of the TIN include [5]: (a) a grid stores the terrain at a uniform resolution while a TIN can

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potentially store large flat regions as single polygons; (b) to construct a grid from irregularly spaced data or multiple source data often requires interpolation that can potentially cause information loss; (c) waterflow on a grid is commonly constrained to fixed directions for ease of computation, which can produce visible artefacts.

Methods for the flow path on a TIN-based DEM are derived from hydrological models on raster [1]. The TIN-based DEM is applied for basin delineation to route the runoff through a watershed using kinematic cascades [6,7]. The TIN edge is used to generate runoff networks by analysing whether the slopes of a common edge forms a ridge, channel or plane [8,9]. The flow paths are calculated along the steepest direction between triangle centres or triangle edges [10-12]. The TIN nodes are also used to describe the flow mode in a respective Voronoi cell [11]; the basin boundary can also be distinguished by Voronoi [13]. In this paper, the proposed FNE flow mode is different from previous flow models. The water on each triangle facet flows to its lowest node first. The flow paths are then traced along the steepest edges until the local minimum point. Meanwhile, the triangles are flagged with the trace path information, that means all the triangles are flagged with the label of pit point. Finally, the basin can be generated according to the same label. From the case studies, the FNE flow mode and its basin division method are verified to be practical and effective.

2. Basin division method

To describe the basin division clearly, several definitions are given as follows[5]: the flow path of a point, which is the steepest descent path that ends either at a local minimum (pit, labelled as P) or the boundary of the terrain; the watershed of the point P, which is the set of all points whose trickle paths contain P; basins, which are defined as watersheds of pits; the outlet point, which is defined as the lowest point among the boundary points of the basin.

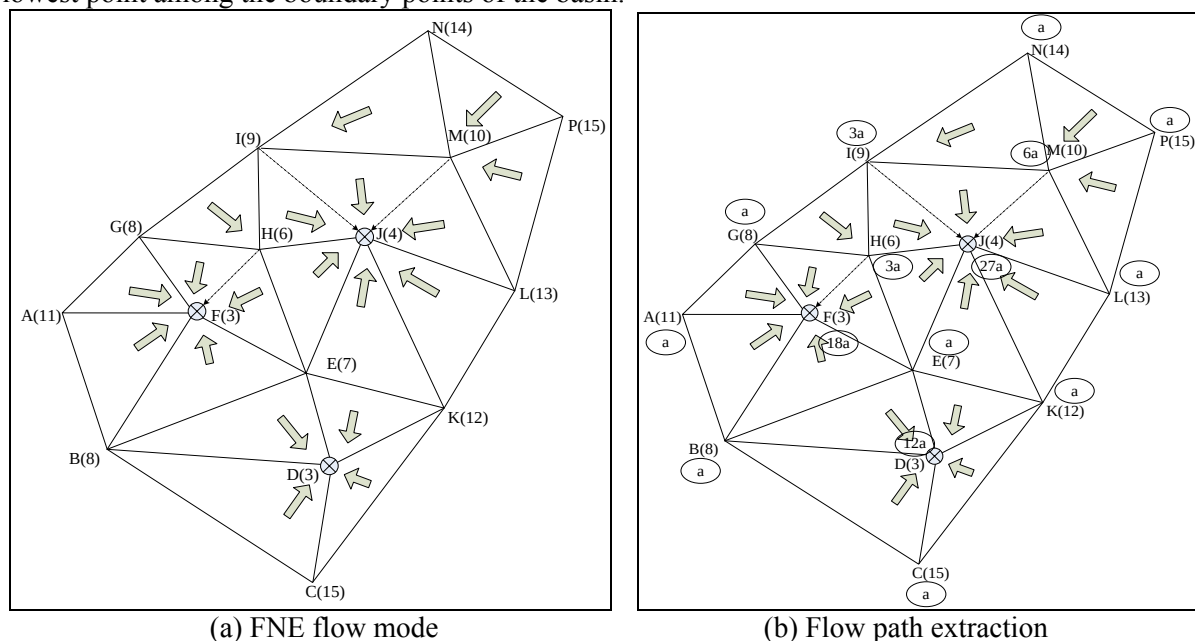


Figure 1. FNE flow mode and related flow path extraction. The number in bracket labels the relative elevation of the point; $\Rightarrow$ labels the direction of water on each triangle flow to its lowest point; $\cdots\rightarrow$ labels the flow path in the basin.

2.1. Face-Node-Edge (FNE) flow mode

The flow path is the premise for basin division. The water flows into the lowest node on each triangle facet, as shown in figure 1(a), unlike previous research with the assumption that the water on each triangle facet initially flows to its edge [5,8,9]. Then, the flow path is traced along the steepest triangle

edges. Meantime, the pit is labelled with the accumulation of the node's water volume. According to the final water volume label for each node, the flow paths can be traced and extracted, as shown in figure 1(b). The detailed FNE flow mode is shown in steps (1) to (6).

- (1) Initialise all the nodes of the TIN model, and label the initial water volume of each node with a ;
- (2) Assign the water on each triangle facet to flow into its lowest node. In other words, the lowest point's water volume label is $3a$, while the other two nodes remain a ;
- (3) Store the lowest points of all triangles in Queue S in order of descending altitude;
- (4) Pop out one of the lowest points P from S , and search the neighbour points. If the altitude of P is lower than that of the neighbour points, the water volume remains the same; otherwise, the water volume of P flows to the steepest neighbour point Q ; namely, the water volume label of Q increase the label of P , while the label of P remains the same. Mark P and Q are searched; afterward, take the point Q to repeat step (4);
- (5) All points in S repeat step (4) to obtain the final water volume labels;
- (6) Take the points whose final water volume labels are more than a to trace the flow path with the ascending order of labels.

2.2. Basin division

According to the FNE flow mode, we labelled the upstream triangles of each flow path to generate basins, shown in figure 2. The procedure of the basin division method is described in the following:

- (1) Obtain the lowest points of all triangles, and store them in List L ; label the upstream triangles of each lowest point;
- (2) If L is empty, then exit. Otherwise pop out the lowest point P ; if P is not searched then go to step (3), otherwise pop out the next point;
- (3) Search the neighbour points of P and add to List N ;
- (4) Compared the altitude of P with points in N , if it is not the local minimum, then go to step (5); otherwise proceed to step (7);
- (5) Calculate the slope between P and the points in N . Search the other node (point M) on the steepest edge and store in List R . Add the upstream triangles of M to the upstream triangles of point P , and label P has been searched;
- (6) Assign point M as point P , then go to step (3);
- (7) Label the point as the pit point and record its upstream triangles;
- (8) According to the recorded upstream triangles to form the basin, each pit only belongs to one basin.

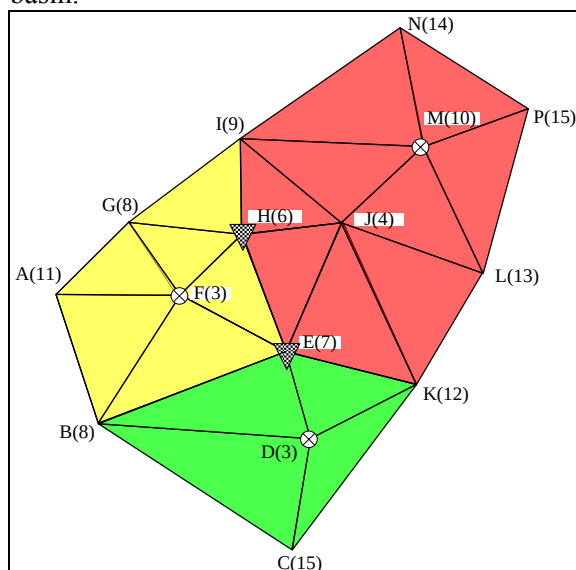


Figure 2. Basin division result. ⊗ the pit point; ▼ the outlet point of each basin.

3. Case study

3.1 Special cases

To verify the correctness of the proposed method, three types of simulated terrain were designed as the experiment cases: a ramp-shape plane, a wave-shape surface, and a two-bowl-like surface, shown in figure 3. All the experiment terrains are represented by TIN models. The basin division results are as shown in figure 4 by employing the proposed method. The results evidently verified the correctness of the basin division method from the cognition.

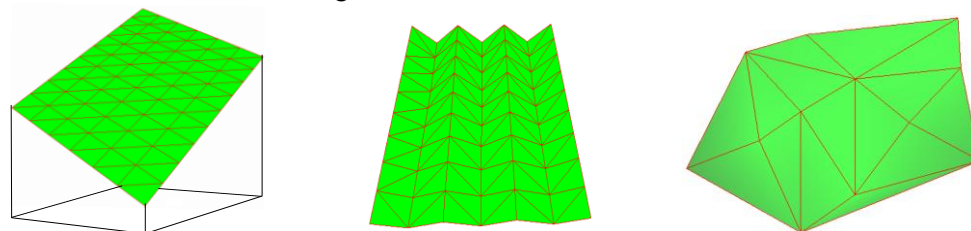


Figure 3. The experiment terrains represented by TIN, ramp-shape plane, wave-shape surface, and two-bowl-like surface.

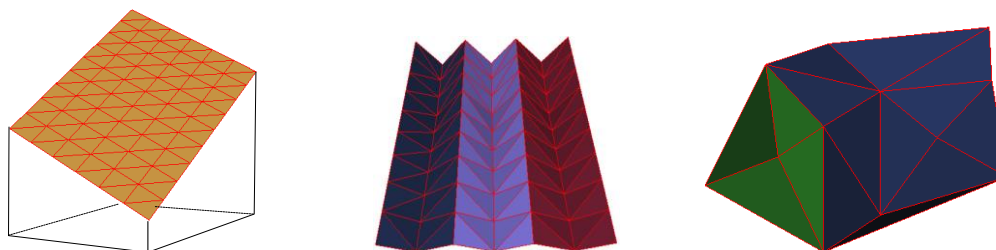


Figure 4. The basin division results of the special cases, different colour means different basins.

3.2 Raster DEM comparisons

For the validation of the proposed basin division method, the typical experiment terrain was represented both in raster and TIN format (shown in figure 5). First, the raster-based DEM was processed by the ArcHydro tool for comparative study. The basin division result is shown in figure 7. Second, the raster cells were converted to regular points to build the TIN-based DEM and to represent the same terrain. Third, we divided the basin by using the proposed basin division method, which was described in Section II. The basin division result is shown in figure 6. There are some differences between the basin division result using the proposed method (figure 6) and using the ArcHydro tool (figure 7). However, the FNE flow mode is more flexible for representing the real ground flow directions; additionally, basin division results had a better basin depiction than those from the raster DEM by ArcHydro tool.

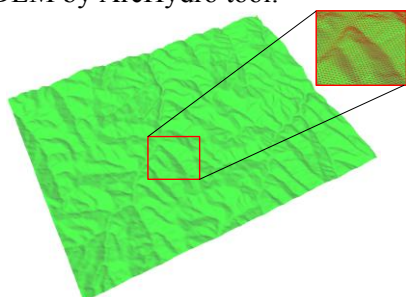


Figure 5. The typical experiment terrain represented by TIN.



Figure 6. Basin division result by FNE flow mode.

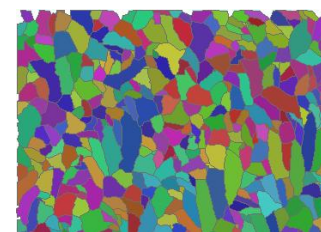


Figure 7. Raster represented DEM basin division by ArcHydro tool.

3.3 Urban basin division

As basic terrain unit for water runoff, basin can serve as the foundation to simulate the flood inundation[5]. When it comes to urban storm flood, the FNE flow mode and basin division method can also provide a solution for urban basin division. Taken the urban terrain surface of main campus of Beijing Normal University as the experimental case, the final basin division result is shown in figure 8. This result can be further employed as the terrain basis for modelling urban surface runoff in urban flood inundation.

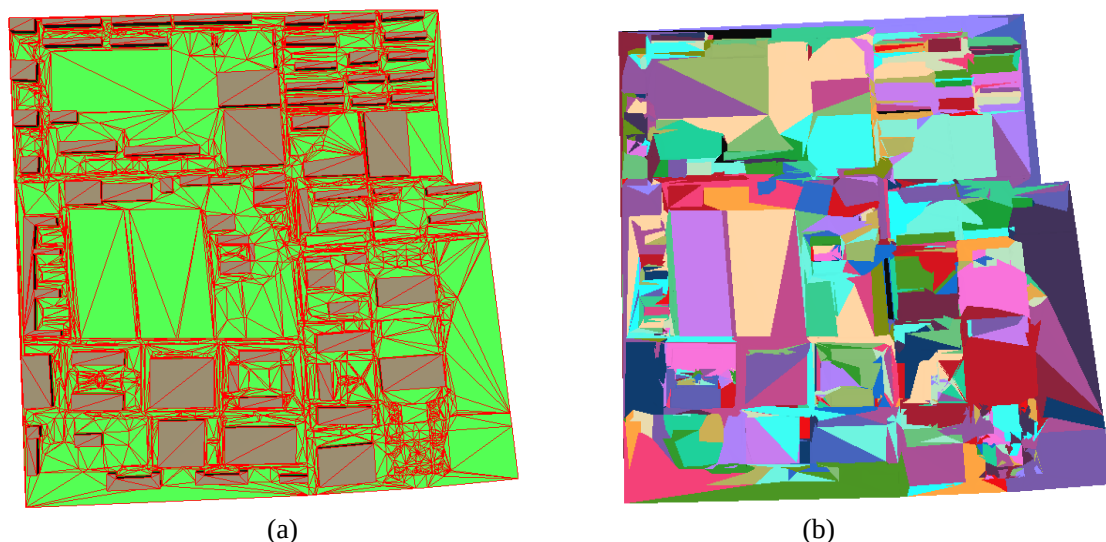


Figure 8. The urban terrain surface of main campus of Beijing Normal University represented by TIN model (a) and its basin division result (b).

4. Conclusion

Although most flow modes as well as basin division research and software focus on raster-based DEM, the TIN-based DEM is evident and has irreplaceable advantages. This paper proposed the FNE flow mode and its basin division method for the TIN-based DEM. Some cases were presented to validate its correctness and usability. From the case studies it was reached that: (1) the FNE flow mode and its basin division method are reasonable; (2) the FNE flow mode and its basin division method can provide better basin depiction than that for raster, e.g., the ArcHydro tool; (3) the method can be employed to provide the runoff unit for urban flood inundation. In consequence, the FNE flow mode can serve as a new flow mode for a TIN-based DEM, and its basin division method can provide new basin depiction. Furthermore, quantitative comparisons with raster experiments will be conducted to validate its usability and feasibility for developing commercial tools.

Acknowledgement

We acknowledge the joint support from Key Program (No.8111003) of Beijing Natural Science Fouds, National Basic Research Program of China under Grant (NO. 2011CB707102), and Fundamental Research Funds for Central Universities under Grant (NO.105565GK).

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