◆ Research Paper

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Design theories and methods for running routes and slopes

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Abstract: Mountain marathon has attracted much attention and love, and its development is changing with each passing day. There is an urgent need for new methods and theories of marathon route development and design. For the safety of participants, the marathon route design needs to meet the requirements of slope and distance. This paper proposes the theory and method of marathon route design, which is embodied as a 5-step design method (downhill trajectory slope of equidistant points, interactive point layout, close route, route check, route adjustment), and further designs the interactive route design program. And a specific example is provided in the text. The 5-step design method and the compiled program have good operability and can complete the design of the marathon route very well. It has an excellent guiding value for the development and design of future marathon routes and can also be used to check the completed marathon routes.

Keywords: marathon route design; Interactive program; slope; route design theory; design method

1. Introduction

Various local departments have designed and constructed many walking and running routes with people's love for sports, some in some city parks and some in the geological park. As shown in the picture, the three running tracks of Beijing Olympic Forest Park are red, yellow and green, as shown in Figure 1.

Local governments have also organized various marathons to attract more social attention and enhance local economic strength. In 2019, 1,828 marathons were held in China, with 7.2 million participants [1, 2], compared with 39 in 2013[2] . At the beginning of 2019, the General Administration of Sports of China released the "Marathon Sports Industry Development Plan", which stated that by 2020, the scale of my country's marathon sports industry would reach 120 billion yuan [3].

Figure 1 Running track in Olympic Forest Park of China
(a) The sightseeing tower and walking/running track in Beijing Olympic Forest Park; (b) 10 km meters sign; (c) 2.5 km and 4.5 meters sign; (d) 10.5 km meters sign

However, behind the rapid development of the marathon industry, there are significant risks and hidden worries. Stretching itself is a risky sport. The most direct one is that a marathon may exceed the physiological limit of ordinary people and cause sudden death. Even in developed countries where the marathon industry is relatively mature, there is a specific fatality rate [4]. According to a study published in the New England Journal of Medicine in January 2012, nearly 11 million people participated in the whole or half marathon in the United States between 2000 and 2010. A total of 59 sudden cardiac arrest events occurred. Of those, 42 died. The fatality rate is approximately four per million [5]. Acute coronary thrombosis [6] and coronary artery occlusion, and sudden cardiac death have been reported in some athletes during marathon running, especially after exercise [7].

The 4th Yellow River Stone Forest Mountain Marathon 100km Cross Country Race and Rural Revitalization Health Run in 2021 will be held on May 22, 2021. It includes three categories: 5km Rural Revitalization Health Run, 21km Cross Country Race, and 100km Cross Country Race. 1,700 people (excluding tourists) participated in the Rural Revitalization and Health Run; 120 people signed up for the 21-kilometer cross-country race, and 93 people participated; 187 people signed up for the 100-kilometer cross-country race, and 172 people participated. During the competition, high-impact weather, such as sudden cooling, precipitation, and strong wind, caused a public safety responsibility incident, resulting in the death of 21 contestants and injuries to 8 [8].

High temperatures in sports also cause some accidents. American football player Jordan McNair died due to heatstroke sustained during practice at the University of Maryland in College Park. An investigation revealed that staff at the university waited more than an hour before calling an ambulance, during which time they failed to cool his body adequately [9].

There are many reasons for the above accidents, and it is necessary to strengthen research from all aspects to avoid the occurrence of marathon accidents. On the one hand, marathon accidents can be studied from the perspective of biology and medicine [5, 6, 10]. On the other hand, the relationship between human energy supply and energy consumption in the marathon route can be studied [11-13]. The slope, distance, and elevation data of the marathon route need to be combined when calculating the energy expenditure of the human body. There is a calculation formula in the human energy supply formula. At the general running speed, the prediction formula of human exercise energy consumption[14, 15] is:

$$M = 1.5W + 2.0(W+L)(\frac{L}{W})^2 + \eta(W+L)[1.5V^2 + 0.35VG] \quad (1)$$

Where: M is the energy consumption rate of the human body (w), W is the body weight (kg), L is the bear load (kg), V is the running speed (m/s), G is the slope (%), η is the surface condition coefficient, η=1 in the case of horizontal hard road and η=2 on loose sand. Figure 3 **a**, **b,** and **c**, and Figure 4 **a**, **b,** and **c**, η=1.2.

Therefore, when calculating the energy supply rate of the human body, it is necessary to consider the marathon's route fully. The main research content of this paper is to study the design of the marathon route. On the one hand, it provides a programmatic method of route design, and on the other hand, it gives a specific example for route design, which can provide a reference for the creation of marathon routes in the future.

2. Route Design Theory and Method

On the topographic map, the slope formula from a point $P_1(x_1, y_1, z_1)$ to another point $P_2(x_2, y_2, z_2)$ is:

$$S = \frac{z_2 - z_1}{\sqrt{\left(x_1 - x_2\right)^2 + \left(y_1 - y_2\right)^2}} \tag{2}$$

In the formula, S is the slope. S>0 means uphill, and S<0 means downhill.

In the actual calculation, the points are selected one by one. To make the analysis accurate, the research in this paper is to arrange the candidate points in the topographic map at equal intervals. There are 8 points around a point, such as J in Figure 2(a), and there are 8 points around E, F, G, I, K, M, N, and O. The distance between adjacent points in the horizontal and vertical directions is d, and the distance between the points on the oblique line is $\sqrt{2}\,d$. Therefore, select the relative distance in the horizontal and vertical directions to have a more intuitive and direct processing of the slope S in the formula (2). Thus, the distances are all d. The path progresses along with horizontal or vertical points and can be advanced step by step to form route points. And a curve that facilitates calculating the travel distance and slope on the route.

The design of the marathon route is to start from the starting point, take the starting point as the center, face the four directions of up, down, left, and right, and select the next point from these four points according to the elevations of the four surrounding points. Taking the new point chosen as the center, choose a point of the three surrounding points except for the previous point as the new path point again. Keep repeating this process until you reach the end of the marathon design.

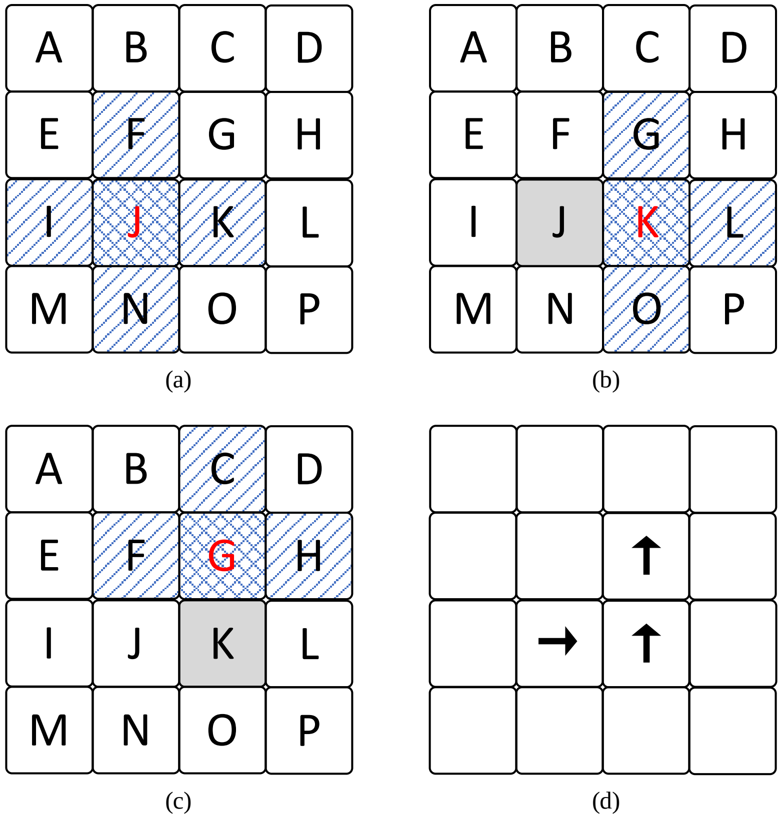

Figure 2 The relationship between adjacent points on the route and the sequence of travel (a), (b) and (c) adjacent points on the route; (d) the travel direction

As shown in Figure 2, A, B, C, ..., P in the figure are the coordinate points in the topographic map, J in Figure 2(a) is the starting point, and there are four points I, K, F, and N around it. According to formula (2), the slopes between point J and four surrounding points are calculated, which are S_I, S_K, S_F, and S_N, respectively. Then according to the design requirements of the slope, mainly according to formula (1), see which one meets the design requirements of the slope, and then determine the position of the next point. Figure 2(b) shows that point K is the next point after point J.

Figure 2(b) shows four surrounding points, but point J is the previous point, so this point is not considered. Then, the corresponding gradient is calculated according to formula (2) from the three points, G, L, and O, and the next point is selected. Figure 2(c) shows that the next point is G.

Through the above calculation and selection of points, the order of the route points can be obtained as J, K, and G as shown in Figure 2(d).

The final Matlab program inter_2.m is shown in Table1.

Table 1 inter_2.m program

```
clear all
z=0.1*load('exampleDEM.txt');
fid=fopen([pwd,'\point_xyz.txt'],'w');
fclose all
j_max=size(z,1);i_max=size(z,2);
x=0:1:i_max-1;y=0:1:j_max-1;
[X,Y] = meshgrid(x,y);
[px,py] = gradient(z);
subplot(1,2,1)
contour(X,Y,z)
hold on
%quiver(X,Y,px,py)
hold on
pause
x_i=70;y_j=170;
fid=fopen([pwd,'\point_xyz.txt'],'a+');
fprintf(fid,'%.10g %.10g %.10g
\n',[x_i,y_j,z(y_j,x_i)]);
fclose all
hold on
subplot(1,2,1)
plot(x_i,y_j,'kO','markersize',4)
plot(x_i,y_j,'k+','markersize',4)
laiyuan=2direction0=3;z1=z;juli_geshu=0;
while direction0~=99
xuhao_juzhen=[x_i,  x_i-1,x_i+1,    x_i,
x_i,laiyuan;
y_j+1,y_j,    y_j,  y_j-1,  y_j,      0] ;
x1_5=[x_i,x_i-1,x_i+1,x_i,x_i];
y1_5=[y_j+1,y_j,y_j,y_j-1,y_j];
new_point1=[z1(xuhao_juzhen(2,1),xuhao_juzh
en(1,1));
z1(xuhao_juzhen(2,2),xuhao_juzhen(1,2));
z1(xuhao_juzhen(2,3),xuhao_juzhen(1,3));
z1(xuhao_juzhen(2,4),xuhao_juzhen(1,4));
z(xuhao_juzhen(2,5),xuhao_juzhen(1,5))]
slope_5=new_point1-new_point1(5)
xianshi=[nan slope_5(1) nan; slope_5(2) 0
slope_5(3);nan slope_5(4) nan];
if laiyuan==1
xianshi(1,2)=inf
elseif laiyuan==2
xianshi(2,1)=inf
elseif laiyuan==3
xianshi(2,3)=inf
elseif laiyuan==4
xianshi(3,2)=inf
end
mm=0;
while  mm==0
direction0=input(['up 1; down 4; left 2; right
3, %99sttp the program']);
if isempty(direction0)
   mm=0;
 elseif (direction0==1
|direction0==2|direction0==3|direction0==4|dire
ction0==99)
   mm=1;
 elseif ~(direction0==1
|direction0==2|direction0==3|direction0==4|dire
ction0==99)
   mm=0;
end
end
if direction0==99
   break
else
result_point=[x1_5(direction0),y1_5(direction0),
new_point1(direction0)];
fid=fopen([pwd,'\point_xyz.txt'],'a+');
fprintf(fid,'%.10g %.10g %.10g \n',result_point);
fclose all
juli_geshu=juli_geshu+1;
subplot(1,2,1)
if mod(juli_geshu,50)==0
plot(x1_5(direction0),y1_5(direction0),'k*','mark
ersize',10) ;%
elseplot(x1_5(direction0),y1_5(direction0),'m.','
markersize',10) ;%
end
shuju_xyz=load([pwd,'\point_xyz.txt']);
%figure(2)
```

```
subplot(1,2,2); plot(shuju_xyz(:,3)) ;%
switch direction0
  case 1
    x_i=x_i;    y_j=y_j+1;    laiyuan=4;
  case 2
    x_i=x_i-1;    y_j=y_j;    laiyuan=3;
  case 3
    x_i=x_i+1;    y_j=y_j;    laiyuan=2;
  case 4
    x_i=x_i;    y_j=y_j-1;    laiyuan=1;
  end
end
end
```

---

3. A case

There is no unit in an area with an east-west width of 98 and a north-south length of 180. In practical applications, the unit can be meters, kilometers, etc. The elevation points in this area are discretely drawn to draw a three-dimensional elevation map, as shown in Figure 3. A deep groove can be seen running along the diagonal of the area, and the contours of this area are shown in Figure 4.

In order to study the overall trend of path elevation in this area, in this area, select a point S1(20, 30), S2(20, 70), S3(20, 110), S4(20, 150), S5 (40, 30), S6(40, 70), S7(40, 110), S8(40, 150), S9(60, 30), S10(60, 70), S11(60, 110), S12(60, 150), S13(80, 30), S14(80, 70), S15(80, 110) and S16(80, 150). According to the downhill, the closest slope to S=-1.2 goes down the mountain. Sixteen routes are drawn, along with distance and elevation maps along the lines, as shown in Figure 4.

As shown in Figure 4, the overall trend is divided into two parts, one part is along the deep diagonal ditch, going down the mountain, and many routes overlap, and this part of the path point is on the hillside facing the deep trench. The other part, going down the mountain, deviates from the center of the area and travels to the area's periphery. This part of the waypoint is on the hillside facing away from the deep ditch. Through these 16 points and the corresponding route path, you can get a preliminary understanding of the direction of the route and the slope of future route design. If you want to go uphill, you need to go against the path, and if you're going to go downhill, you need to follow the way, which has an excellent guiding effect on the design of the route.

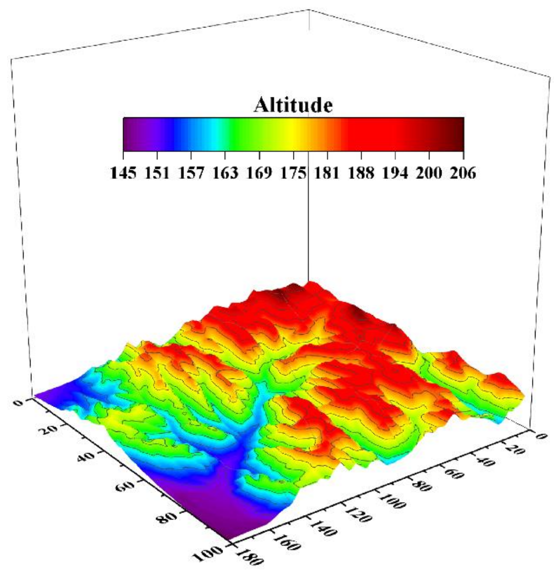

Figure 3 Three-dimensional elevation map

(The unit of height can be m, 10 meters, etc., and the units of x, y-axis can be meters, kilometers, etc.)

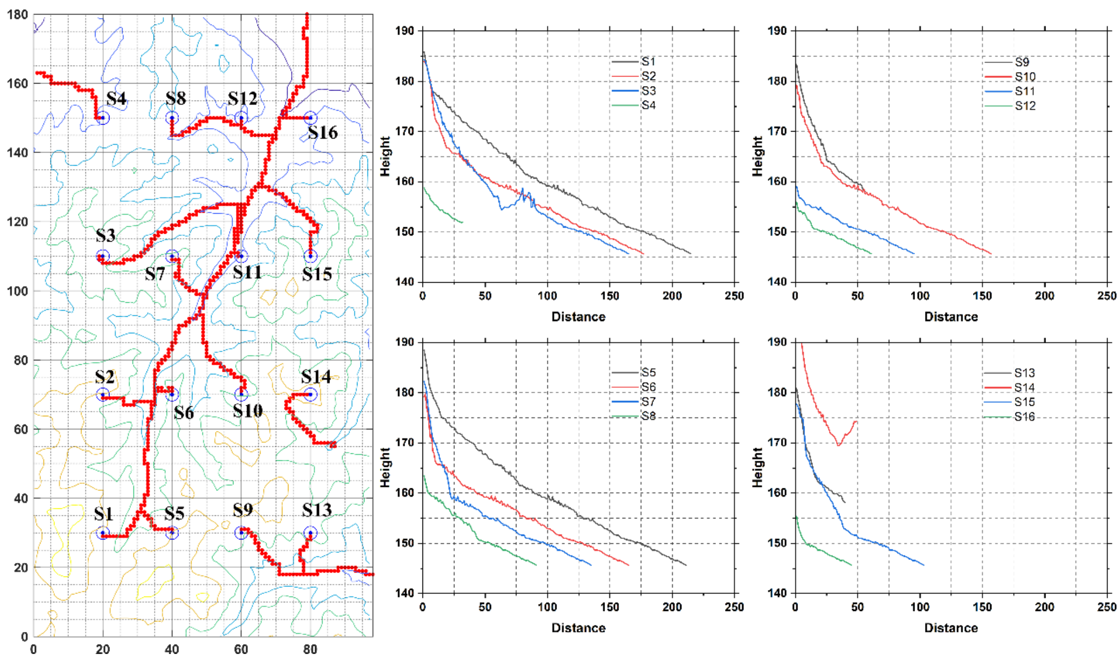

Figure 4 Topographic contours, 16-point downslope paths, and elevations along each path

Further, the route design for this area is carried out, as shown in Figure 5.

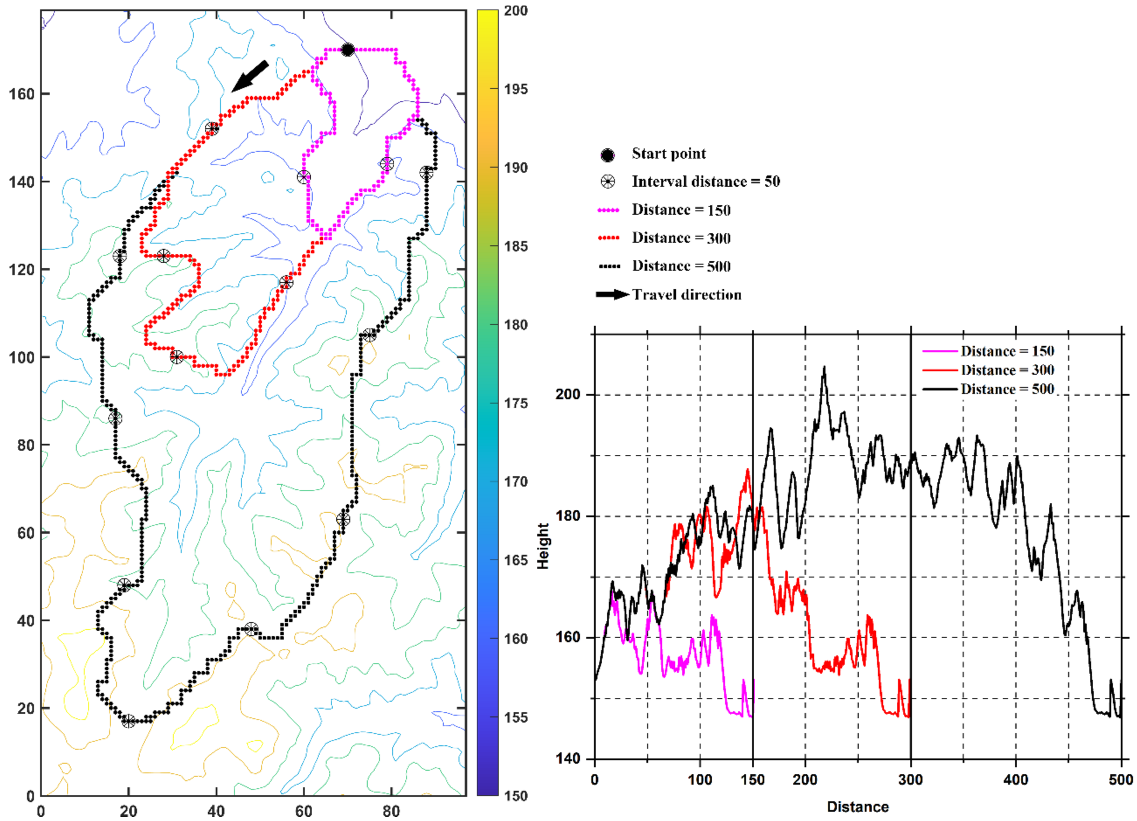

Figure 5 Three marathon routes

There are three routes, 150, 300, and 500, with a typical start and end section. Also, plot the elevation along each route. In terms of height, as a whole, each way is first uphill and then downhill.

Designing a marathon route generally needs to meet several conditions: (1) the length of the line meets the established distance; (2) the slope meets the requirements: on the one hand, the slope cannot be continuously uphill, the distance of the continuous uphill cannot be too large, and the continuous uphill Afterwards, there needs to be a certain distance of downhill or flat road; on the other hand, it cannot go downhill continuously. After the continuous downhill, there needs to be a particular flat road or uphill; that is, it needs to meet the interval matching of uphill-downhill-flat road.

In the specific design of the route, it is divided into the following steps: (1) According to the topographic map in advance, there are regular equidistant points from the map, and starting from these points, according to a particular slope, downhill or uphill, Obtain the overall downhill or uphill trajectory at this point, such as S1, S2, S3, ..., S16 in Figure 4, these points are more dense; (2) According to the starting point, and according to the S point According to the program developed in this paper, the route points are interactively laid out one by one; (3) The points are constantly wandering, and finally return to the starting point to form a closed route; (4) According to the distance-elevation curve drawn synchronously , check whether the continuous uphill distance and continuous downhill distance meet the requirements; at the same time, check whether the maximum slope meets the requirements; (5) If the slope and distance requirements are not met, according to the data files stored synchronously, for the corresponding points, according to the steps (1) The similar downward slope rule of S point in 1), adjust the route point again; finally meet the slope and distance requirements of the route.

The above 5-step design steps are summarized into a 5-step design method: downhill trajectory slope of equidistant points, interactive point layout, close route, route check, and route adjustment. The specific step flow chart is shown in Figure 6.

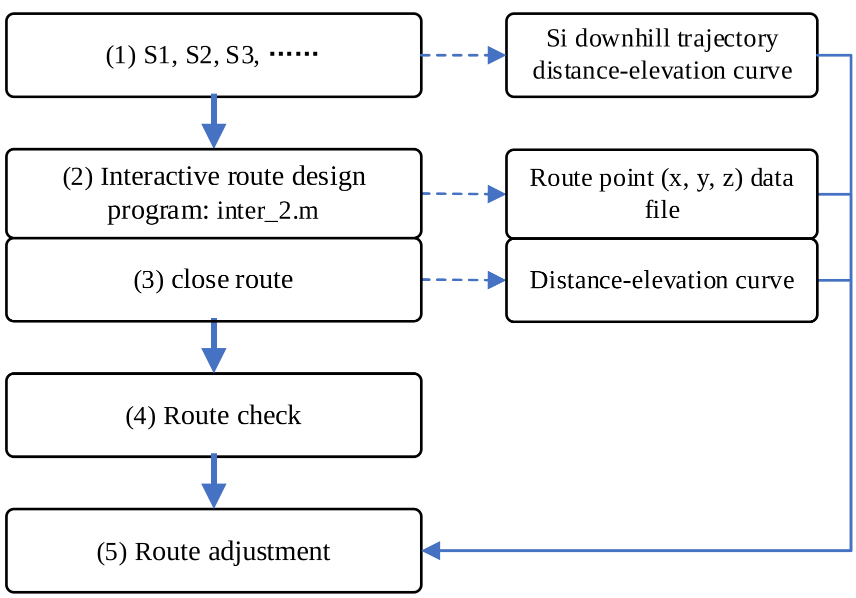

Figure 6 Five-step design method of the route design process

4. Conclusion

The scientific nature of mountain marathon route design is essential, and good route design may significantly reduce the occurrence of marathon accidents. The design theory and 5-step design method proposed in this paper (downhill trajectory slope of equidistant points, interactive point layout, close route, route check, route adjustment) has good operability and a specific program-assisted design, which can satisfactorily complete the design of the marathon route. It has an excellent guiding value for the development and design of future marathon routes and can also be used to check the completed marathon routes.

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