boundary conditions by the following partial difference equation,

$$\Phi_{(i,j)} = (\Phi_{(i+1,j)} + \Phi_{(i-1,j)} + \Phi_{(i,j+1)} + \Phi_{(i,j-1)})/4, \qquad (2)$$

where i = position on the grid in the x direction, j = position on the grid in the y direction. The direction of the largest descent α is determined by means of the field values of surrounding grid points as follows;

$$\alpha = a\tan 2\left(\frac{\Phi_{(i,j-1)} - \Phi_{(i,j+1)}}{\Phi_{(i-1,j)} - \Phi_{(i+1,j)}}\right). \qquad (3)$$

Then using α, the x and y components of the straight line between two successive points are calculated; this line starting from the current point and ending at the next point is drawn in the direction of the largest descent.

3. Following the path points

Following the path means keeping the ends of the links on the path. Figure 1 shows a robot link and a small portion of the path. To follow the path, the end of the link, point B, is made to approach to the path points by calculating the shortest distance BC numerically.

Before the link moves, starting from the second point of the path, the distance from point B to this point is calculated and compared with the distance from point B to the first point. If the distance for the second point is shorter than the one for the first point, the procedure continues. The distance from point B to the third point is calculated and compared with the second one. If it is shorter than the second one, the next point is taken into account and the procedure continues. Otherwise, the procedure stops and the second point is taken as the shortest distance BC.

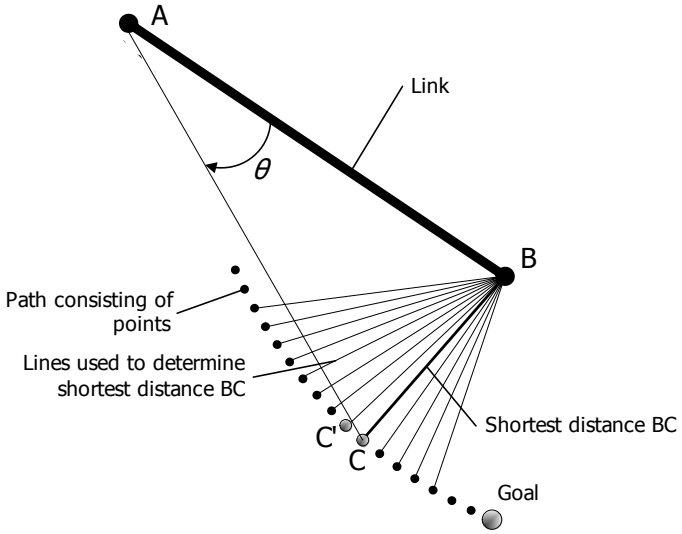

Figure 1. Finding shortest distance, angle and direction of rotation

Using the coordinates of point C and the shortest distance BC that have just been determined, distance AC can be calculated. Since all of the sides of triangle ABC are known, angle α is determined by means of cosines theorem. If α is more than a fixed value E, the link is rotated by E. If it is less than E, the link is rotated by α itself. In other words, the link is rotated as much as required, preventing shaking. One final note is that the above procedure is carried out for each link and its path at each increment.

3.1. Propagation procedure through links

The relationship between robot links is attained by way of a propagation procedure carried out through links. Suppose that the end-effector, i.e. snake's head, is taken as link i. It is moved repeatedly until its tip reaches the path. When the link reaches the path, the link is said to be settled. Then, link (i-1) is moved and link i is settled again. As soon as (i-1) is settled, link (i-2) is moved and both link (i-1) and link i are resettled. This procedure continues until the base link which is the furthest link in the opposite side of the snake's head is reached. Therefore, the robot achieves first part of the snake-like motion.

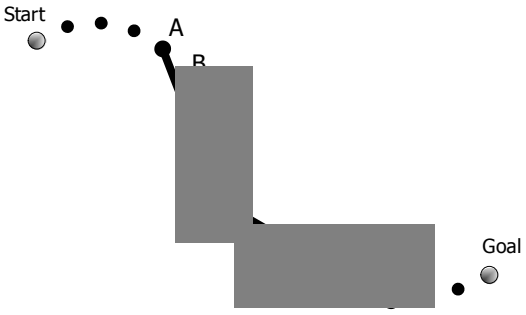

Figure 2. Two subsequent configurations of a two link snake-like robot