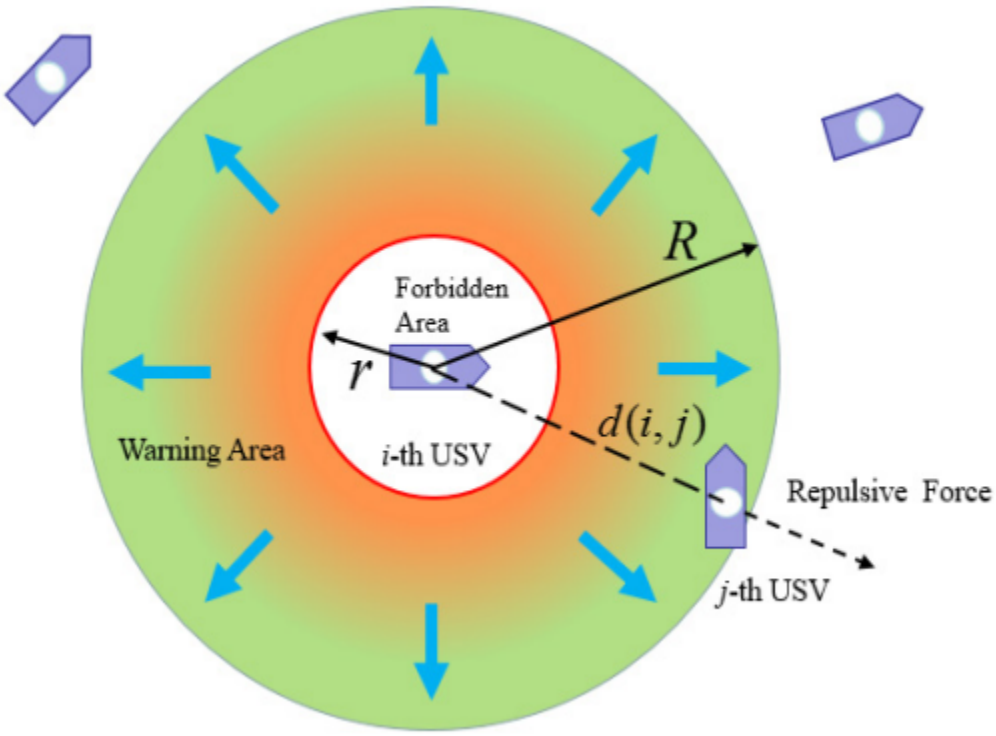
Q6.

it is ideal for each vessel to perform unified avoidance manoeuvres when encountering an obstacle ship. However, due to the considerable distance between each vessel during the mission, it is a reasonable strategy that one or more vessels may need to perform independent avoidance manoeuvres without affecting any other members of the swarm. Such behaviour, where each vessel determines the operation of its actions according to its own state, may lead to conflicts within the swarm. Therefore, no collision among USVs that occurs during swarm motion should be considered; it is imperative to take measures to prevent collisions between vessels within the swarm. Noting that it has been assumed that each USV can obtain its neighbour's relative information through the detection and positioning equipment, the collision avoidance method based on APF is applied in the process of multi-pursuers encirclement. The collision avoidance area consists of a forbidden area and a warning area, as shown in Figure



The avoidance function is introduced as

$$V_{coll,i} = \left(\min(0, \frac{d(i,j)^2 - R^2}{d(i,j)^2 - r^2} \right)^2 \quad i,j = 1,2,\cdots,n. \quad i \neq j$$

where d(i, j) represents the radius of the USV circular forbidden area to ensure the safety of the USV. The warning area is a ring-shaped area with an inner radius of r and an outer radius of R; other USVs in this area will be forced away to eliminate the potential risk of collision. The collision-free controller is as follows:

$$F_{coll,i} = -\sum_{i=1}^{n} \nabla V_{coll,i},\ i = 1,2,\ldots,n \quad i,j = 1,2,\cdots,n.\ i \neq j$$

where the gradient of Vcoll, i (t) is given as

$$\nabla V_{coll,i} = \begin{cases} \text{not defined} & r = d(i,j) \\ 4\frac{(R^2 - r^2)(d(i,j)^2 - R^2)}{(d(i,j)^2 - r^2)^3}(\boldsymbol{P}_i - \boldsymbol{P}_j), & r < d(i,j) < R \\ 0, & d(i,j) > R \text{ or } d(i,j) < r \end{cases}$$

There is no repulsion force between USVs outside the warning area. In the warning area, the repulsion force increases rapidly the closer the distance is between the two USVs. The repulsed USV gradually moves away from the adjacent USV until it moves outside the warning area.