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# A novel motion coordination method for variable-sized multi-mobile robots

**Key words:** Multi-mobile robot system; Collision avoidance;  
Deadlock avoidance; Glued nodes; Motion coordination

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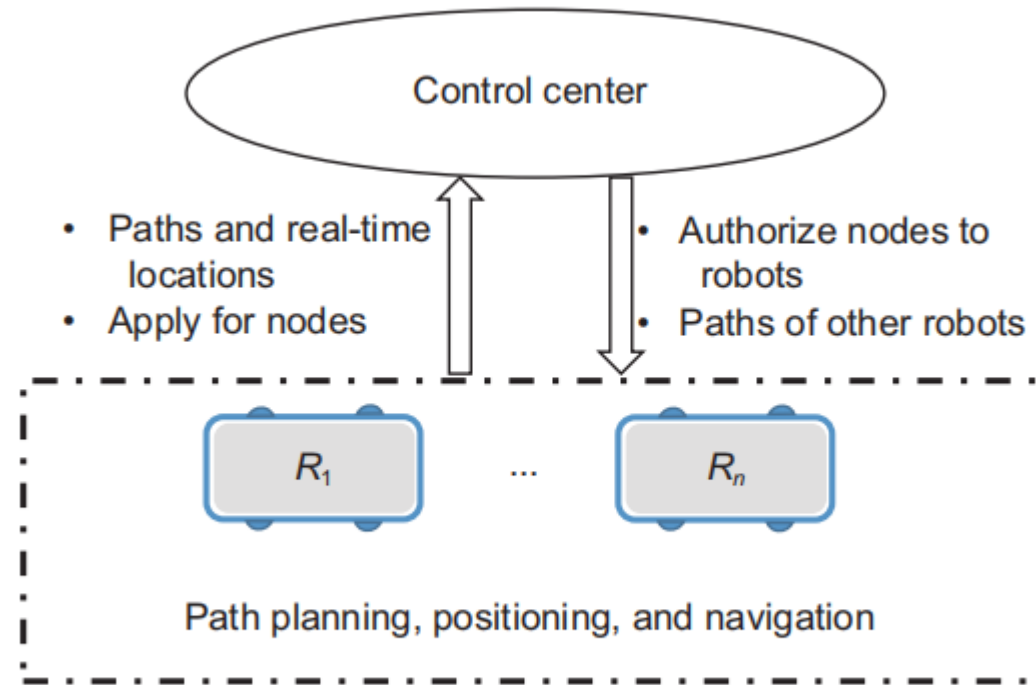
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# Motivation

1. **Motion coordination** includes collision and deadlock handling, which is an overwhelmingly significant issue in multi-mobile robot systems (MMRSs).
2. In some scenarios, robot sizes are different when loaded and unloaded, which means that the robots are **variable-sized**, making motion coordination more difficult.
3. The **zone-control-based methods** are not accurate enough for variable-sized multi-mobile robots and reduce the efficiency of the system.

# Method



**Fig. 3** Architecture of the multi-mobile robot system

# Method (Cont'd)

The **glued relationship** between two nodes varies with different robot sizes and different paths.

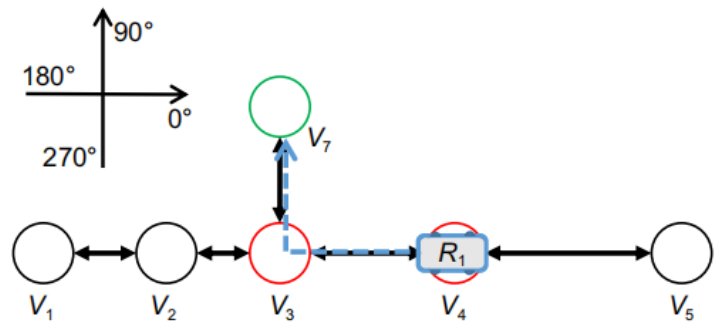


Fig. 2 An example of the path of robot  $R_1$  ( $V_4$  and  $V_3$  are authorized to  $R_1$ )

**Definition 1** (Occupied nodes) The nodes for which a robot  $R_i$  has obtained authorization from the control center are called occupied nodes, denoted as  $OV_i$ .

**Definition 2** (Applying nodes) The nodes for which a robot  $R_i$  applies to the control center are called applying nodes, denoted as  $AV_i$ .

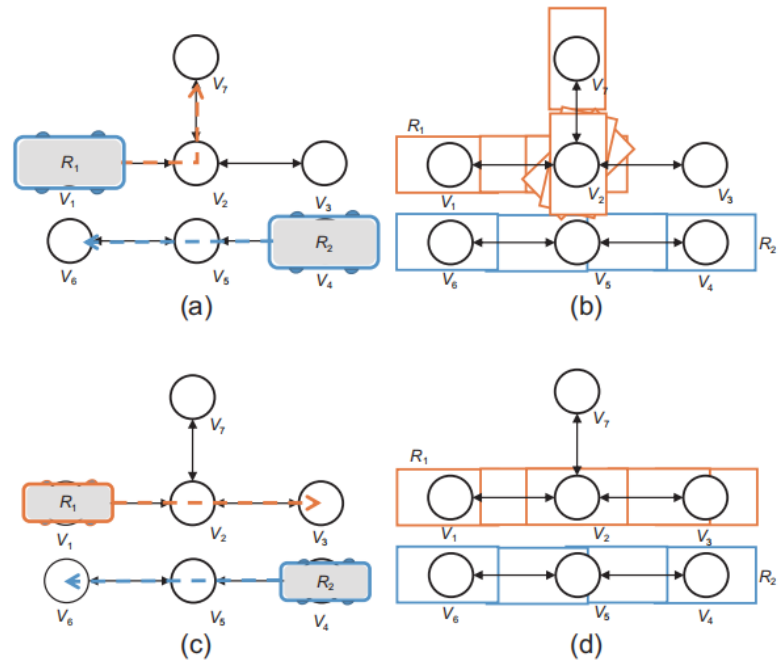


Fig. 6 An example showing the characteristics of the glued nodes: (a) paths of the two robots contain a pair of glued nodes,  $GN_{2,5}^{1,2} = 1$ ; (b) areas swept by the two robots when executing  $\Gamma_1^2$  and  $\Gamma_2^5$  corresponding to (a); (c) paths of the two robots do not contain glued nodes; (d) areas swept by the two robots when executing  $\Gamma_1^2$  and  $\Gamma_2^5$  corresponding to (c)

# Method (Cont'd)

The **collision avoidance algorithm** avoids collisions among robots.

**Theorem 1**  $\forall V_m \in OV_i$  and  $\forall V_n \in OV_j$ , if  $OV_i \cap OV_j = \emptyset$  and  $GN_{m,n}^{i,j} = 0$ , then  $R_i$  and  $R_j$  are collision-free.

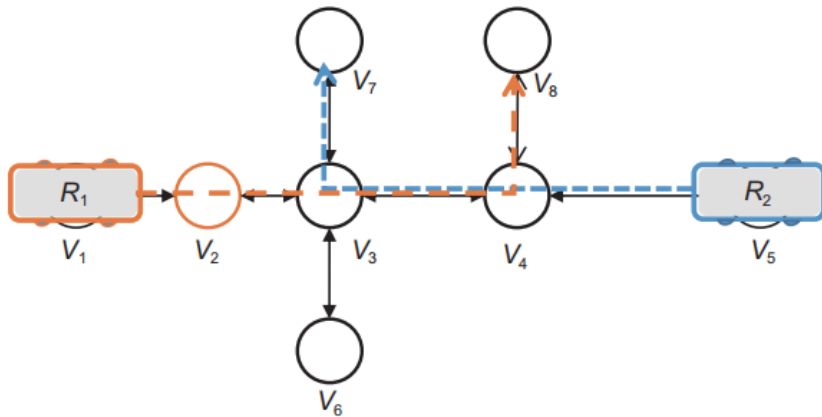


Fig. 7 An example of collision avoidance

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**Algorithm 1** Collision avoidance:  $CA(R_i, AV_i)$

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1: Input: robot  $R_i$  and its applying nodes  $AV_i$ 
2: Output: AN
   // nodes without collision
3: Initialization:  $AN = \emptyset$ 
4: for  $V_m$  in  $AV_i$  do
5:   if  $O_m \notin \emptyset$  then
6:     return AN
7:   end if
8:   for  $R_j$  in  $R$  do
9:     if  $R_j \neq R_i$  then
10:      for  $V_n$  in  $OV_j$  do
11:        if  $GN_{m,n}^{i,j} = 1$  then
12:          return AN
13:        end if
14:      end for
15:    end if
16:  end for
17:  add  $V_m$  to AN
18: end for
19: return AN

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# Method (Cont'd)

The **deadlock avoidance algorithm** avoids direct and impending deadlocks among robots.

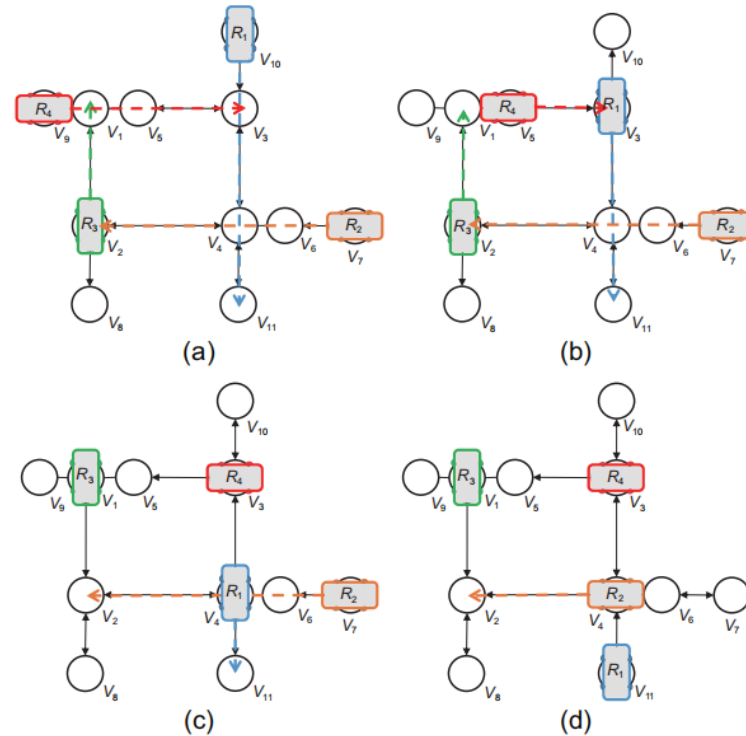


Fig. 9 An example of collision and deadlock avoidance for four robots: (a) conflict occupations ( $R_3 \rightarrow \Phi_{3,4}$ ), blocks ( $R_3 \rightarrow R_4$ ), glued nodes ( $GN_{1,9}^{3,4}=1$ ,  $GN_{1,5}^{3,4}=1$ ,  $GN_{4,6}^{1,2}=1$ ); (b) conflict occupations ( $R_3 \rightarrow \Phi_{3,4}$ ,  $R_4 \rightarrow \Phi_{4,1}$ ,  $R_2 \rightarrow \Phi_{2,3}$ ), blocks ( $R_3 \rightarrow R_4$ ,  $R_4 \rightarrow R_1$ ), glued nodes ( $GN_{1,5}^{3,4}=1$ ,  $GN_{4,6}^{1,2}=1$ ); (c) conflict occupations ( $R_1 \rightarrow \Phi_{1,2}$ ), blocks ( $R_1 \rightarrow R_2$ ); (d) no conflict occupations, no blocks, and no glued nodes

# Method (Cont'd)

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**Algorithm 3** Collision and deadlock avoidance:  
CDA( $R_i$ ,  $AV_i$ )

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```
1: Input: robot  $R_i$  and its applying nodes  $AV_i$ 
2: Output: DAN
   // nodes without collisions or deadlocks
3: Initialization: DAN =  $\emptyset$ 
4: AN = CA( $R_i$ ,  $AV_i$ )
5:  $V_s \in \emptyset$ 
6: flag=true
7: for  $V_m$  in AN do
8:   if  $V_m$  not in any conflict areas then
9:      $V_s = V_m$ 
10:    flag=false
11:   end if
12: end for
13: for  $V_m$  in AN do
```

```
14:   if flag=false then
15:     if  $V_m = V_s$  then
16:       flag=true
17:     end if
18:     add  $V_m$  to DAN
19:     continue
20:   end if
21:   add  $V_m$  to  $OV_i$ 
22:   if  $R_i \rightarrow \Phi_{i,j}$  then
23:     if a conflict circle containing  $R_i \rightarrow \Phi_{i,j}$  is
        generated then
24:       break
25:     else
26:       add  $V_m$  to  $OV_i$ 
27:     end if
28:   else
29:     add  $V_m$  to DAN
        //  $V_m$  not in any conflict areas
30:   end if
31: end for
32: return DAN
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# Conclusions

1. We propose the concept of **glued nodes** based on the roadmap. The concept of glued nodes is related to the real-time paths and sizes of robots.
2. We propose **a hybrid control architecture**, by which the robots and the control center interact using the application and authorization of nodes.
3. We analyze the difference between direct deadlock and impending deadlock, and present **collision and deadlock avoidance algorithms** based on the concept of glued nodes.



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