

Zichao XING, Xingkai WANG, Shuo WANG, Weimin WU, Ruifen HU,
2023. A novel motion coordination method for variable-sized multi-
mobile robots. *Frontiers of Information Technology & Electronic
Engineering*, 24(4):521-535. <https://doi.org/10.1631/FITEE.2200160>

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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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

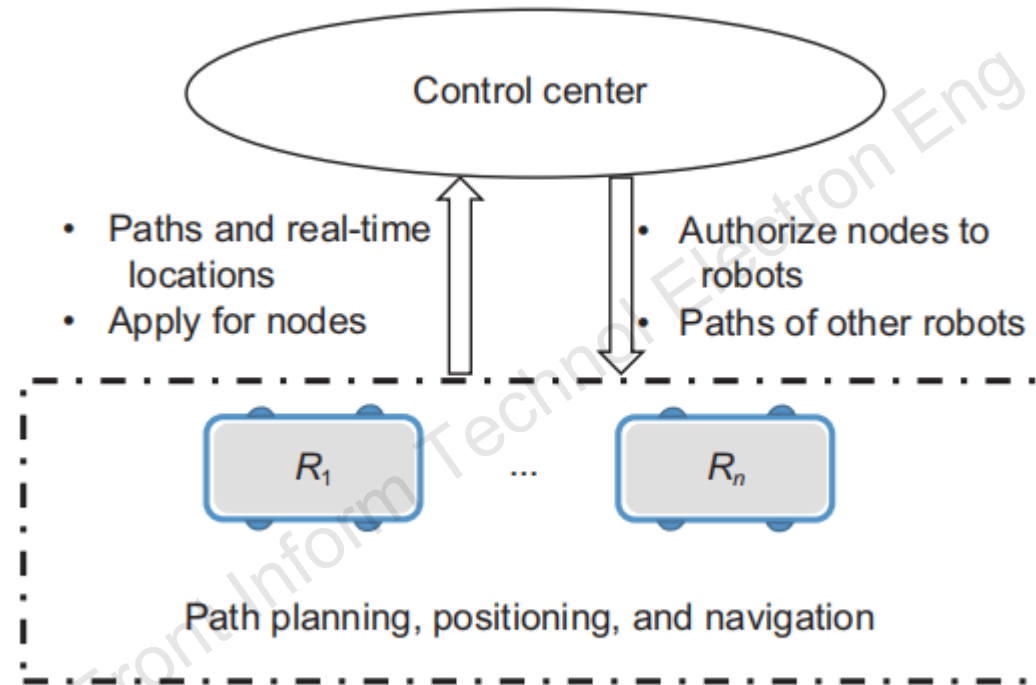


Fig. 3 Architecture of the multi-mobile robot system

Method (Cont'd)

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

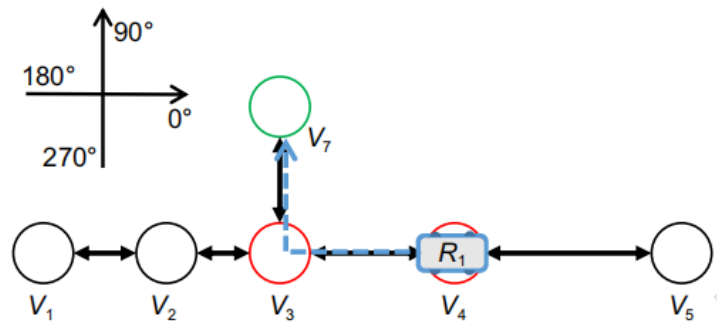


Fig. 2 An example of the path of robot R_1 (V_4 and V_3 are authorized to R_1)

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 .

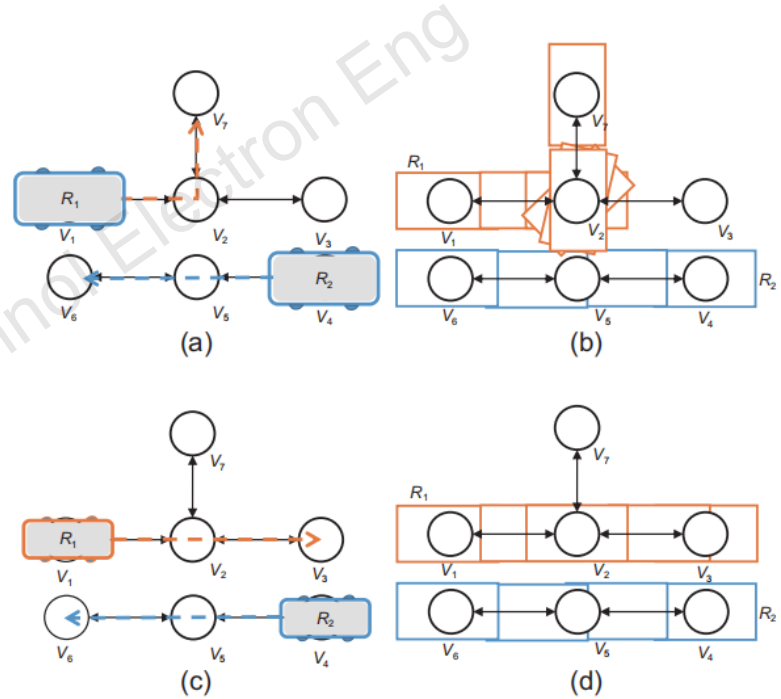


Fig. 6 An example showing the characteristics of the glued nodes: (a) paths of the two robots contain a pair of glued nodes, $GN_{2,5}^{1,2} = 1$; (b) areas swept by the two robots when executing Γ_1^2 and Γ_2^5 corresponding to (a); (c) paths of the two robots do not contain glued nodes; (d) areas swept by the two robots when executing Γ_1^2 and Γ_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.

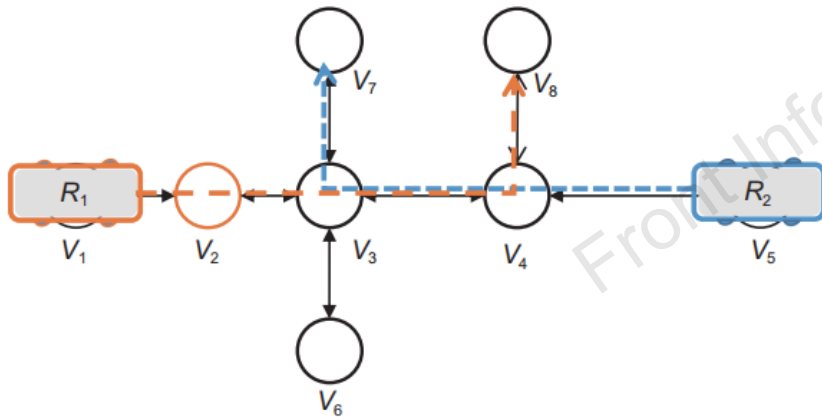


Fig. 7 An example of collision avoidance

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

```

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

```

Method (Cont'd)

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

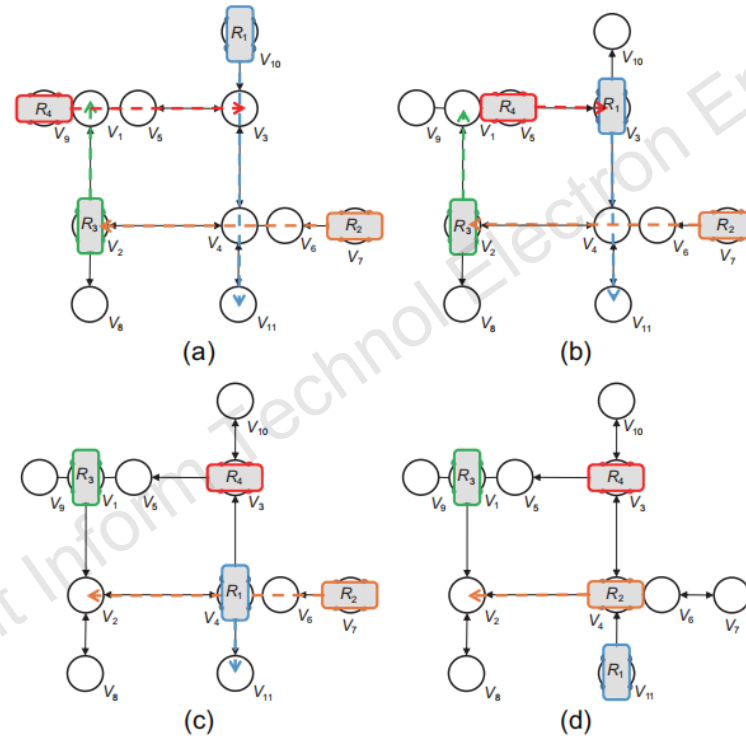


Fig. 9 An example of collision and deadlock avoidance for four robots: (a) conflict occupations ($R_3 \rightarrow \Phi_{3,4}$), blocks ($R_3 \rightarrow R_4$), glued nodes ($GN_{1,9}^{3,4}=1$, $GN_{1,5}^{3,4}=1$, $GN_{4,6}^{1,2}=1$); (b) conflict occupations ($R_3 \rightarrow \Phi_{3,4}$, $R_4 \rightarrow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

Method (Cont'd)

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

```
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
```

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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