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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

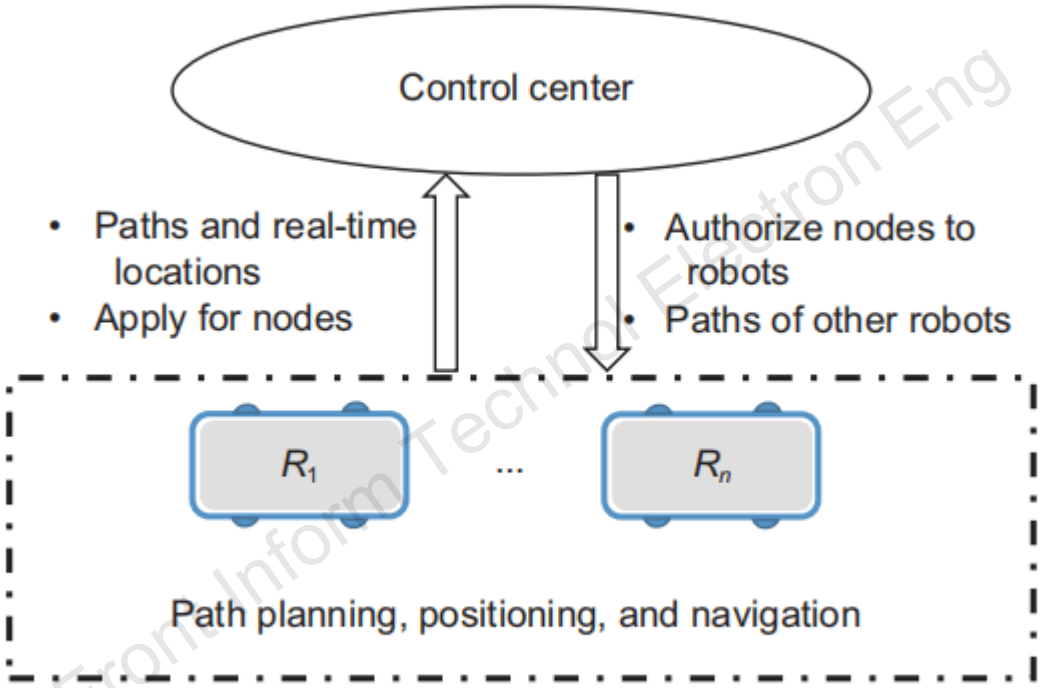
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Motivation

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.

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Method



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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.

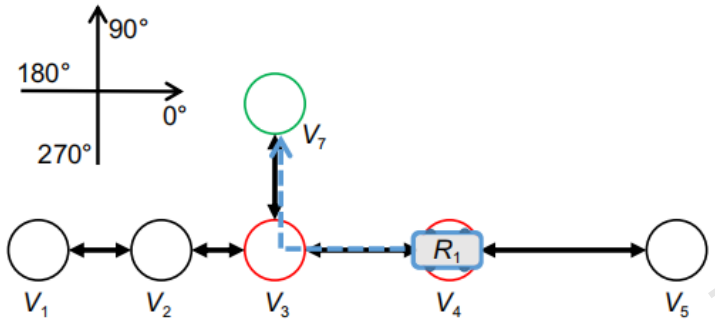


Fig. 2 An example of the path of robot R_1 (V_4 and V_3 are authorized to R_1)

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.

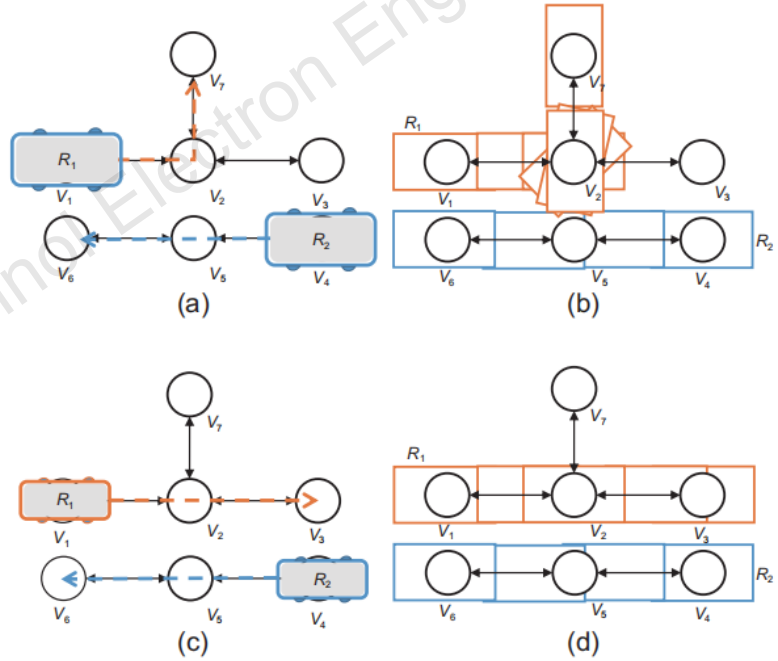


Fig. 6 An example showing the characteristics of the glued nodes: (a) paths of the two robots contain a pair of glued nodes, $\mathrm{GN}_{2,5}^{1,2} = 1$; (b) areas swept by the two robots when executing Γ_1^2 and Γ_2^5 corresponding to (a); (c) paths of the two robots do not contain glued nodes; (d)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

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Method (Cont'd)

The collision avoidance algorithm avoids collisions among robots.

Theorem 1 $\forall V_m \in \mathrm{OV}_i$ and $\forall V_n \in \mathrm{OV}_j$, if $\mathrm{OV}_i \cap \mathrm{OV}_j = \varnothing$ and $\mathrm{GN}_{m,n}^{i,j} = 0$, then R_i and R_j are collision-free.

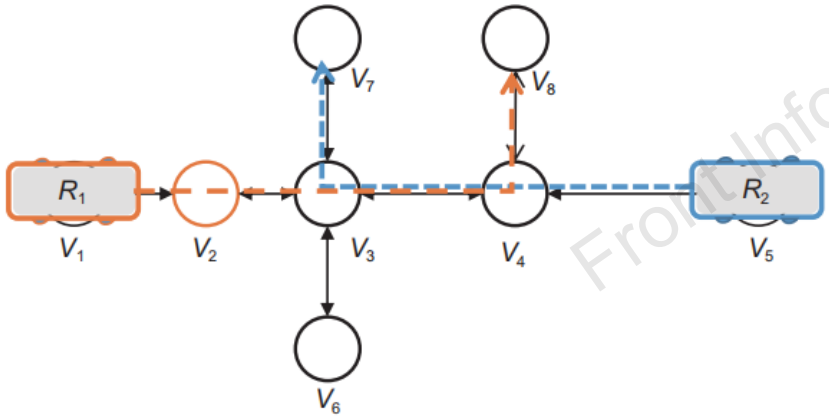


Fig. 7 An example of collision avoidance

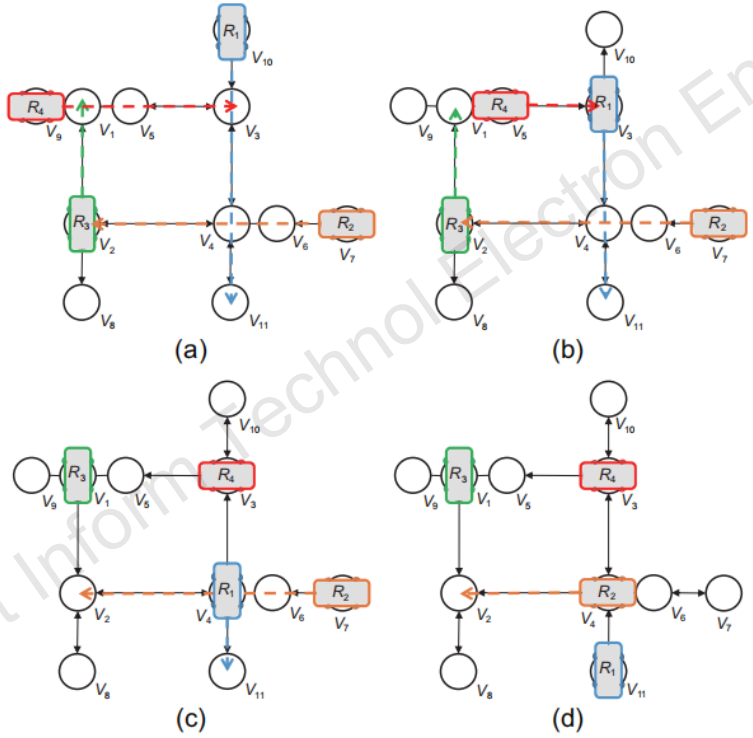
Algorithm 1 Collision avoidance: $\mathrm{CA}(R_i, \mathrm{AV}_i)$

Input: robot R_i and its applying nodes AV_i
Output: AN
// nodes without collision
Initialization: AN$= \varnothing$
for V_m in AV_i **do**
  if $O_m \notin \varnothing$ **then**
    return AN
  end if
  for R_j in R **do**
    if $R_j \neq R_i$ **then**
      for V_n in OV_j **do**
        if $\mathrm{GN}_{m,n}^{i,j} = 1$ **then**
          return AN
        end if
      end for
    end if
  end for
  add V_m to AN
end for
return AN

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Method (Cont'd)

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



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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 ($R_1 \rightarrow R_1$); (d) no conflict occupations, no blocks, and no glued nodes

Method (Cont'd)

Algorithm 3 Collision and deadlock avoidance: CDA(R_i, AV$_i$)

Input: robot R_i and its applying nodes AV$_i$
Output: DAN
// nodes without collisions or deadlocks
Initialization: DAN= $\varnothing$
AN= CA(R_i, AV$_i$)
$V_s \in \varnothing$
flag=true
for V_m in AN **do**
  if V_m not in any conflict areas **then**
    $V_s = V_m$
    flag=false
  end if
end for
for V_m in AN **do**
  if flag=false **then**
    if $V_m = V_s$ **then**
      flag=true
    end if
    add V_m to DAN
    continue
  end if
  add V_m to OV$_i$
  if $R_i \rightarrow \Phi_{i,j}$ **then**
    if a conflict circle containing $R_i \rightarrow \Phi_{i,j}$ is generated **then**
      break
    else
      add V_m to OV$_i$
    end if
  else
    add V_m to DAN
    // V_m not in any conflict areas
  end if
end for
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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