Target Assignment Strategy for Scattered Robots Building Formation

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Abstract

This paper presents target assignment strategy for multiple robots that are scattered in the environment and they are expected to build ordered formation. Described approach is general and can be used together with variety of trajectory planning methods. Presented approach lay some constrains for trajectories generation, however, in most cases constrains can be easy satisfied. Simulation results for Hilare-type holonomic robots are presented. Possibility of use for group of nonholonomic mobile robots is also discussed.

Keywords: target assignment, formation building, cooperation of robots, formation of robots, mobile robots.

1 Introduction

Major part of work in field of muilti-robot cooperation in last years was focused on trajectory tracking problem for formation of robots. Through this time few approaches for multiple robot coordination was developed: virtual structure approach [2], [4]- [8], behavioral approach [10]- [17] and leader follower scheme [1], [3] (often treated as coupling of first two approaches). Each of the approaches has some advantages and weaknesses. A large majority of known solutions belong to one of specified sets of approaches, some own features of more then one approach [9]. Detailed comparison of approaches to multi-robot coordination was presented in [18].

In typical behavioral approach each of robots is equipped with autonomous agent. The agents execute tasks basing on predefined rules and information form the sensors. Behavioral approaches are suitable for tasks that can be disassembled to independent subtasks, e.g. moving large quantities of small objects, mapping and exploration of unknown areas.

Virtual structure approach is also named "virtual rigid body" or "virtual leader". In this approach all robots of the formation keep fixed distance to the other robots of the formation. External centralized controller synchronizes motions of entire formation. This approach is suitable for tasks that can't be executed by single robot and can't be disassembled to independent subtasks, e.g. common moving of large objects.

At present stage of development in field of multi-robot systems it seems to be possible that presently known methods will be developed in the future. Each of them has some advantages and is suitable for particular classes of tasks. It is fairly possible that in practice they will be implemented together and the methods will be switched depending on characteristic of the task which multi-robot system has to execute.

Method presented in this paper concern multi-robot system that can operate using both previously mentioned methods. High-level controller switches control method depending on characteristics of the task. Switching of the control method from virtual structure to behavioral does not require any additional activities because behavioral methods assure self-reorganization of the formation, however, inverse switching usually is difficult because virtual structure methods assume that initially formation is put in order. We provide method that together with appropriate trajectory planning method can be successively used for building ordered formation by the robots that are scattered in the environment.

In section two we present the target assignment strategy. This method assigns robots to the target points in desired formation and moreover generates information about adequate succession of the execution of path tracking by robots to avoid collision and necessity of bypass maneuvers. In subsection 2.1 we presented the algorithm, in subsection 2.2 we show detailed analysis of the method, in subsection 2.3 we point out the limitations of the method.

In section three we present simulation results for Hilare-type holonomic robots. Trajectory planning method that is used in this example is very simple. We assume that robot moves along segment line between its initial configuration and target point that was assigned to it. Robot changes its orientation at initial point to enable straight motion to the target point. When the robot reaches target point it changes its orientation to desired. This simple trajectory planning method enable to show how target assignment strategy works.

In section four we analyze possibility of use proposed target assignment strategy for formation of nonholonomic mobile robots.

2 Target assignment strategy

2.1 Algorithm

Let's denote: D_{ij} - generalized "distance" between i-th robot and j-th point of desired formation, R - set of robots, T - set of target points of the desired formation, RT - set of robots that achieved their target points, RN - set of robots that did not achieved their target points, $R = RT \cup RN$, $RT \subset R$, $RN \subset R$, TR - set of target points of the desired formation that are assigned to the robots, TN - set of target points of the desired formation that are not assigned to the robots, $T = TR \cup TN$, $TR \subset T$, $TN \subset T$, p - priority of currently processed robot, R_i - i-th robot of the formation, T_j - j-th target point of the desired formation.

We assume that the number of robots is equal to the number of target points in desired formation (that is the number of elements in set R and in set T is equal).

The meaning of "distance" D_{ij} depends on specific trajectory planning method. In simple case of Hilare-type holonomic robot, when the robots can move along line segment between initial configuration and final configuration the "distance" is the line segment length.

Before target assignment strategy start execution we have: $RN \equiv R, RT = \varnothing, TN \equiv T, TR = \varnothing$.

The target assignment strategy algorithm is as follows:

$p := 1$;
while ($TN \neq \varnothing$) do
begin
  find $R_i \in RN$ whose distance to the nearest $T_j \in TN$ is greater then for any other robot in RN;
  assign target T_j to robot R_i;
  move R_i from set RN to set RT and move T_i from TN to TR;
  assign priority p to the robot R_i;
  $p := p + 1$
end;

2.2 How it works

In this subsection we use simple example to show in detail how target assignment strategy works. We analyze case where desired formation has only two target points. The number of robots is equal to the number of target points. This simple example owns the same common properties as more complex cases (exemplary simulation results are shown in section 3).

Let's analyze how target assignment strategy generates information about adequate succession of the execution of path tracking by robots to avoid necessity of bypass maneuvers. At figures 1 and 2 we show robot R1 and desired formation of two target points T1 and T2. We hachured area where second robot R2 is positioned.

After first execution of the loop of the algorithm (fig. 1) robot R1 has priority 1 (lowest value) and can be assigned to the target T1 or T2 (robot R1 is positioned at the edge of hachured area unecessarily at position it is drawn). This imply robot R2 is present in hachured area at the center of the figure. The value of priority of robot R2 is 2. It means that robot R2 has right of way before robot R1.

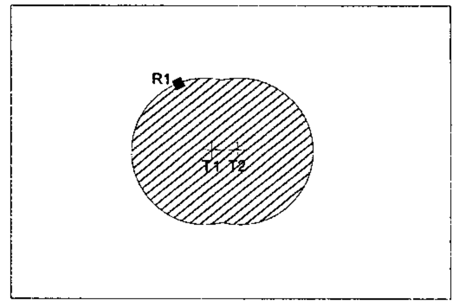

Figure 1:

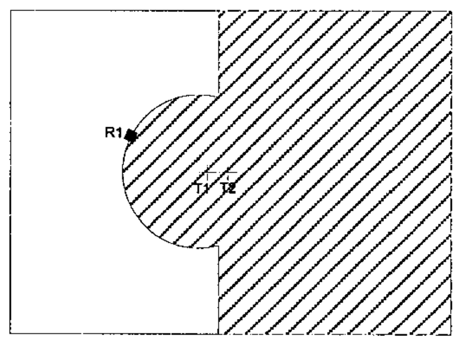

Figure 2:

First execution of the loop of the algorithm (fig. 2.) assigned robot R1 to the target T1 and R1 has priority 1 or 2. This imply robot R2 is present in hachured area on the right. Comparing figures 1 and 2 it is easy to realize that in presented case it is not necessary to make bypass maneuvers because when robot R2 is nearer to the target it moves first and when it is farther it is easy to generate trajectories that are absolutely collision-free.

2.3 Limitations

Presented approach in its common form has some limitations. It works properly when distance between robots and desired formation is "far enough". Now we will explain what it minds.

At the figure 3 we show similar example as in previous subsection. Robot assigned to the target point T1 is positioned at the edge of hachured area. Robot assigned to the target point T2 is positioned in hachured area. Arrows points areas where can appear some perturbations when distance between robots and desired formation is not "far enough". When robot assigned to the robot T1 is positioned near vertex pointed by one of arrows and second robot is positioned near to it inside circled area the collision may occur because of non-zero dimensions of robots. In more complex cases collisions may occur even if we assume that robots are as small as points. Described limitation acts when target assignment algorithm works but not when robots tracks trajectories.

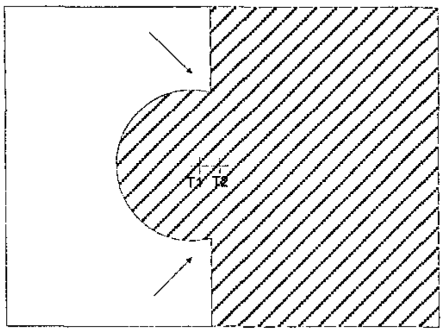

Figure 3:

This problem can be bypassed by "repulsion" of robots "far enough" to the target formation before we start target assignment algorithm. This is not elegant but allowed as obtain interesting simulation results.

Better solution is to modify assignment algorithm. We investigated that limitations can by partly removed using approach that is in some sense complementary to previously presented one:

p := number of robots;
while ($TN \neq \varnothing$) do
begin
  find $T_i \in TN$ which its distance to the nearest $R_j \in TN$ is greater then for any other target in TN,
  assign robot R_j to the target T_i;
  move T_i from set TN to set TR and move R_i from RN to RT;
  attribute priority p to the robot R_j;
  $p := p - 1$
end;

That strategy works properly when robots are "near enough" to the desired formation. Presently we are not able to properly unify or switch both methods to assure entirely collision-free target assignment.

3 Holonomic robots example

Now we present simulation results for Hilare-type holonomic robots. We assume that robots move along segment line between its initial configuration and target point that was assigned to it. Robot changes its orientation at initial point to enable straight motion to the target point. When robot reaches target point it changes its orientation to desired. This simple trajectory tracking method enable to show how target assignment strategy works. This motion tracking method is very simple, however, can be used for Hilare-type holonomic mobile robot.

To assure proper succession of motion of the robots planned trajectory for each robot is surrounded by area that is forbidden for other robots that have lower priority. When robots move along trajectories their forbidden areas are shrinking. When farther motion of robot will violate forbidden area of robot with higher priority the motion is suspended and then violation condition is periodically checked.

In our simulations we employed rectangular forbidden areas that surrounded planned linear trajectories. At fig. 4 we show two robots (denoted using digits) and two target points (denoted using letters). Robot 1 has lower priority and is assigned to its nearest target point A because it is positioned father to the desired formation. Robot 2 has higher priority and is assigned to the target point B. Robot 2 moves straight to the target point B. Robot 1 movies straight to the target point A, however, it periodically checks if its motion may violate forbidden area of robot 2. When such situation occurs robot 1 suspends its motion.

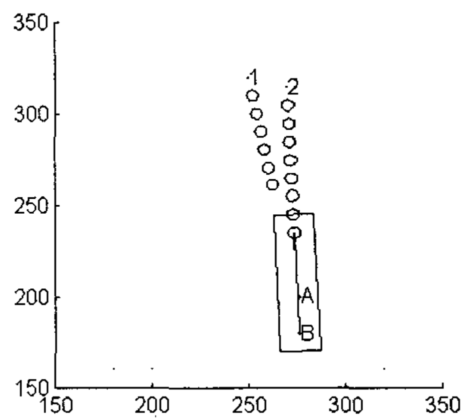

Figure 4:

At fig. 5 we present simple example for desired formation with nine target points and nine robots. The initial positions of robots cause that planned trajectories are not crossed, but when dimensions of robots are sufficiently big there can occur collision of robots 1 and 2 with robot 9. In accordance with previously described method robots 1 and 2 suspends its motion when they may violate forbidden area of robot 9. Robot 9 has highest priority and has right of way before all other robots.

At fig. 6 we present similar example. In this case all robots are positioned at one side of the desired formation. At first robots 1, 2 and 3 are assigned to the target points A, B and C. Then robots 4, 5 and 6 are assigned to the robots D, E and

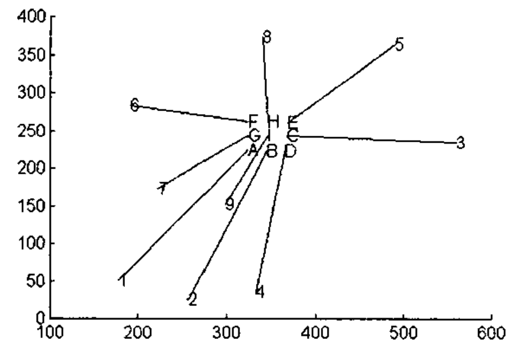

Figure 5:

F. Finally robots 7, 8 and 9 are assigned to the target points G, H and I. The succession of motion of robots is reverse: robot 9 with highest priority moves first, then robots 8, 7 and so on.

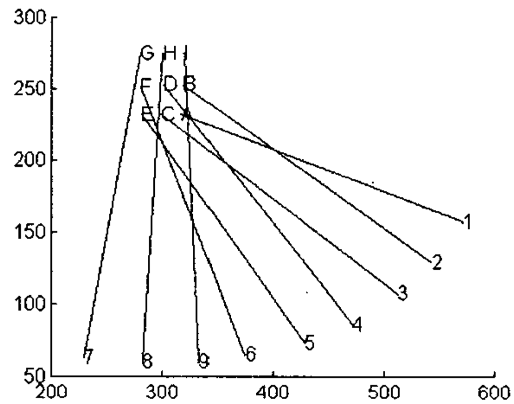

Figure 6:

At fig. 7. we present example in which planned trajectories may looks a little chaotically, however, they was planned using previously described methods. Desired formation may be successfully reached tracking these trajectories.

4 Nonholonomic robots discussion

In this section we discuss possibility of use of target assignment strategy with nonholonomic robots. At figure 8 two robots are shown (denoted using digits) and two target points (denoted using letters). Robot 1 is assigned to the target point A and robot 2 (with higher priority) to target point B. Generally robots can not perform linear tracks because of nonholonomic constrains. We can choose as forbidden area for robot 2 circle with center in target point B and radius length equal to the distance between robot 2 and target

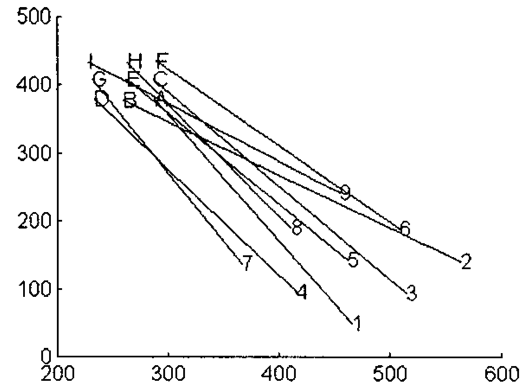

Figure 7:

point B. When we lay some additional condition for shapes of trajectories we can assure that formation building will be executed without bypass maneuvers. Mentioned condition is that the function of distance between robot and target point must decrease in whole range.

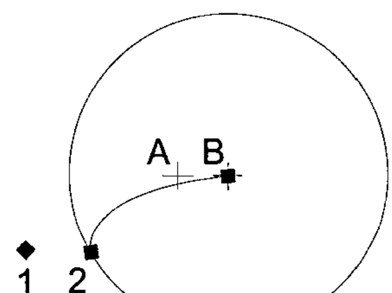

Figure 8:

For example kinematic car satisfies condition of decrease of the distance when it can move forward and backward and is able to turn with radius of curvature that is less then radius of forbidden area. When robot is far form the target point assumption of second condition is easy to be satisfied, however, when robot approaches the target point radius decreases and in the extreme this condition is difficult to be satisfied. It can be done if we constrain orientation of the robot as robot approaches target point.

Formation building and motion control for multiple robots is much more complex in nonholonomic robot case then in holonomic one. Presented analysis is very general, however, it is preface for our future work.

5 Conclusion

Target assignment strategy that can be used together with variety of path planning methods was presented. It is worth to emphasize that the trajectories tracking task with checking of priorities of robots can be executed parallel by controllers assembled on the robots.

There is obviously problem of accuracy and integrity of knowledge about environment. When we use global sensor system, for example video camera that observe entire task space, the problem seems not to be very difficult. When robots use their own sensors problem is much more difficult because robots must sense not only positions of robots and obstacles but also priorities of other robots. Of course robots must be somehow marked to identify their priorities by other robots. Problem is much simpler when system comprise global map of the environment that is shared by robots. The weakness of such solution is that robots use knowledge about environment that is available remotely. The damage of communication channel can imply incorrect operation of robots.

Important weakness of presented formation building method is necessity of centralized execution of some algorithm activities. Our future study concern distributed formation building, however, presently it is not clear it can be executed efficiently.

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