GEOMETRIC FORMATIONS FOR A TEAM OF MOBILE ROBOTS
Odometric-based Maintenance Method for Heterogeneous Teams of Robots

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Abstract: One of the most important topics in multirobot formations is how to maintain the initial formations while the robots are moving or navigating through the environment. This paper presents a new approach based on the cooperation among a team of heterogeneous robots for the maintenance of multirobot formations. The robots must cooperate among them in order to get that all the robots, despite their sensory power, can maintain the formation while they are moving. To get that, the robots only have available the communication among them and their own odometry information. One of the robots, the conductor, is in charge to drive the formation and the rest of robots must follow it maintaining the formation. To do that, the use of "virtual points" and Bezier curves are introduced.

1 INTRODUCTION

A considerable amount of research has been focused on the problem of coordinated motion and cooperative control of multiple autonomous robots. Researchers have been trying to understand how a group of moving robots can perform collective tasks. In fact, this is one of the most popular fields of study in multirobot systems in the last years, with some applications that are well understood including multirobot path planning (Yamashita et al., 2000), formation generation (Arai et al., 1989), and formation keeping (Balch and Arkin, 1998).

Coordination among a group of robots can be very useful for many applications. One of the most important tasks is, in motion coordination, how to move a team of robots in an ordered way, such as maintaining a predefined formation. One of the first approximations to multirobot formations is the leader-follower approach (Das et al., 2002; Liu et al., 2005) where one robot is selected as the leader and must be followed by the rest of robots.

In this field, two works (Chiem and Cervera, 2004; Renaud et al., 2004) were developed at the Robotic Intelligence Lab in Castellón. These works were useful as the basis for the work explained in this paper.

The application described in this paper is a continuation of the previous ones but extended to multiple types of formations by using virtual points. The main idea is to make it feasible for a heterogeneous team of four robots to navigate through an environment in such a way that the robots with sensory power help the robots without it, that is, cooperating among them.

The control for the maintenance of the formation is performed using a decentralized process, where each follower robot decides which movements must be performed in order to follow the movements of the conductor robot, which is specialized in navigation because it is using a laser range-finder and is ahead in the formation. Its actual position while it is moving is sent to every follower robot. When receiving the position, each follower robot calculates the virtual point that it must follow. This virtual point consists of a displacement in the position of the conductor robot that allows it to create different formations, not only the leader-follower line formation.

Once the virtual point is calculated, the follower robot computes the trajectory it must follow in order to arrive from the current position to the estimated conductor robot relative position. For the calculation of this trajectory, Bezier curves are considered, as in (Chiem and Cervera, 2004; Renaud et al., 2004).

2 MAINTENANCE OF THE FORMATION

In this section it is described how a formation can be maintained while the robots are moving in the envi-

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ronment. The formation is composed of a maximum of four robots, where one of them, the conductor, is equipped with a laser range-finder that allows it to navigate in buildings and follow a path determined from the map of the building, the goal point, and the obstacles. The rest of robots have limited visibility, that is, they only know their actual position.

Each robot determines its position in order to maintain the formation with respect to the leader or a displacement of the position of the leader, with a "virtual" point. Also, they use a relative frame of reference, that is, they do not use an absolute positioning system, only the robot with the laser uses an absolute system in relation with the map that it uses to navigate. And in relation with the communication capabilities, the robots can share local and global information to compensate for their limited visibility, in fact, the global information shared among the robots is the actual position of the robot with the laser, and the local information is the actual position of each robot.

In the formation, the position of the robot followers can be controlled by the position of the conductor if all the robots are arranged in a line formation. In other cases, when the followers are positioned to the right or left of the conductor, virtual points are added to the system, as explained in (Chiem and Cervera, 2004). These virtual points are calculated by applying a displacement in the conductor position to the left or to the right, depending on the desired formation. The followers, in this case, instead of following the conductor must follow these virtual points. This arrangement is shown in Figure 1.

In the approach here proposed to achieve the maintenance of the formation, it is desired that robots could perform the task using only the odometry in conjunction with communication to estimate the position of the conductor with respect to each follower. The conductor, by means of the localization task is

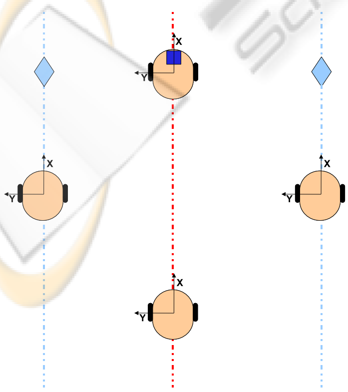

Figure 1: Formation using virtual points as reference for followers.

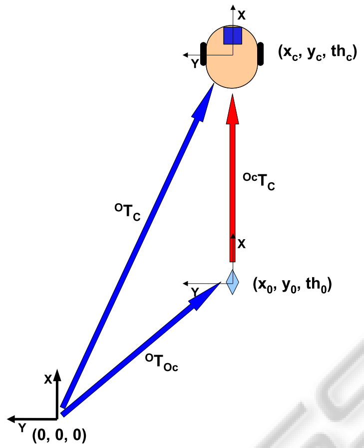

Figure 2: Calculation of the local position of the conductor.

always correctly localized in the map, and it is assumed that it will follow a predefined trajectory, with a constant, known linear velocity. In order for another robot to follow the conductor, the linear and angular velocities need to be computed at each time step. It must be noted that the linear velocity of the follower robots is not constant, due to the different radius of their respective trajectories or because their position may be relatively further back or further forward in the formation.

In order to calculate the linear and angular velocities that allow the followers to move following the movement of the conductor and maintaining the formation, it is necessary to construct the corresponding Bezier curve that defines the trajectory to be followed by the robot. To compute the Bezier curve two positions are needed, the current position of the follower and the current position of the conductor in relation to the follower.

The conductor, at each step sends its own position to the followers. The conductor is always localized in the map by means of the localization task, so, when it requires information about its position, this is done with the coordinates of the map. The followers are not localized on the map, so the only information they have available is their position on their own local system which is determined by the origin that is fixed by their initial position. So, the conductor must transform their global position into a position in its local system. In Figure 2, the necessary relationships to transform the global position into a local position can be seen.

From the figure, it can be deducted that to calculate the position in the local system it is necessary to know the origin of the trajectory in the global system and the actual position of the robot in the global system.

$$^{Oc}T_C = \left(^{O}T_{Oc}\right)^{-1} \cdot {}^{O}T_C \quad (1)$$

where $^{Oc}T_C$ is the actual position of the conductor in the local system, $^{O}T_{Oc}$ is the origin of the trajectory in the global system, and $^{O}T_C$ is the actual position of the conductor in the global system. This last position is updated continuously by the localization task so that the robot have always its current position on the map.

The conductor sends its current position calculated in this way to each follower. When the followers receive the position of the conductor, they need to calculate the position of the conductor in relation to themselves in order to use that information to generate the Bezier curve necessary to calculate the velocities which allow them to move maintaining the formation.

Each follower knows its original displacement in the formation. This information in conjunction with the current position of the follower and the current position of the conductor allows the robots to calculate the relative position of the conductor in relation with the follower. In Figure 3, the necessary relationships to compute the conductor position are shown.

In this case, from the figure, the following equation to calculate the conductor position in relation with the follower $^{F}T_C$ can be obtained,

$$^{F}T_C = \left(^{Of}T_F\right)^{-1} \cdot {}^{Of}T_{Oc} \cdot {}^{Oc}T_C \quad (2)$$

where $^{Of}T_F$ is the position of the follower in its local system, $^{Of}T_{Oc}$ is the position of the origin of the conductor's trajectory in relation to the origin of the follower's trajectory. This value is indicated by the displacements assigned to the position of each robot

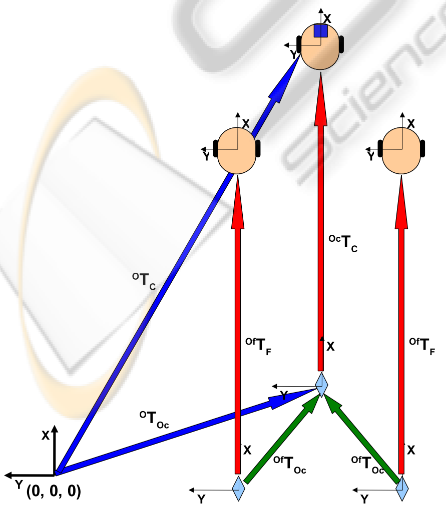

Figure 3: Calculation of the conductor's position in relation to the followers.

in the creation of the formation. And finally, $^{Oc}T_C$ is the position of the conductor in its local system. This is the position that the conductor sends every step to the followers.

Once this position is calculated, it is possible to compute the Bezier curve between the current position of the follower and the position calculated for the conductor. It is at this moment when the virtual points are calculated, if applicable, applying the following formulas,

$$\begin{aligned} x &= x - \sin(\delta) \cdot dy \\ y &= y + \cos(\delta) \cdot dy \end{aligned} \quad (3)$$

where (x, y, δ) is the position of the conductor in relation to the follower, and dy is the displacement in the y axis to be applied. This generates a new point, the virtual point, which will be used to compute the Bezier curve that drives the movement of the follower.

From the Bezier curve computed, the linear and angular velocities can be obtained. The angular velocity can be computed from the curvature of the curve, and the linear velocity is computed in order to maintain the distance from the conductor, applying a gain factor proportional to the current distance from the conductor robot. If the robots is nearer than a predefined distance in the formation, it will move slower, and if the robot is further than the predefined distance, it will move faster.

3 TESTING AND RESULTS

The approach presented in this paper has been tested simulating a team of robots consisting of four Pioneer-2 mobile robots with different features mounted on them, constituting therefore a heterogeneous group. In particular, only one robot is equipped with a laser range-finder sensor and the rest of robots do not have any type of exteroceptive sensors.

The formation control is developed in Acromovi (Nebot and Cervera, 2005), a framework specially designed for the development of distributed applications for a team of heterogeneous mobile robots. The software architecture gives us the ease of development of cooperative tasks among robots, using an agent-based platform.

In Figure 4, some examples executed for different formations shapes are presented together with the formation in which the robots are organized. Formations from two robots up to four robots can be used.

As it can be seen, the odometry-based approach is suitable for the development of applications using multirobot formations. From the examples, it can be infered that the behaviour of the robots is as desired,

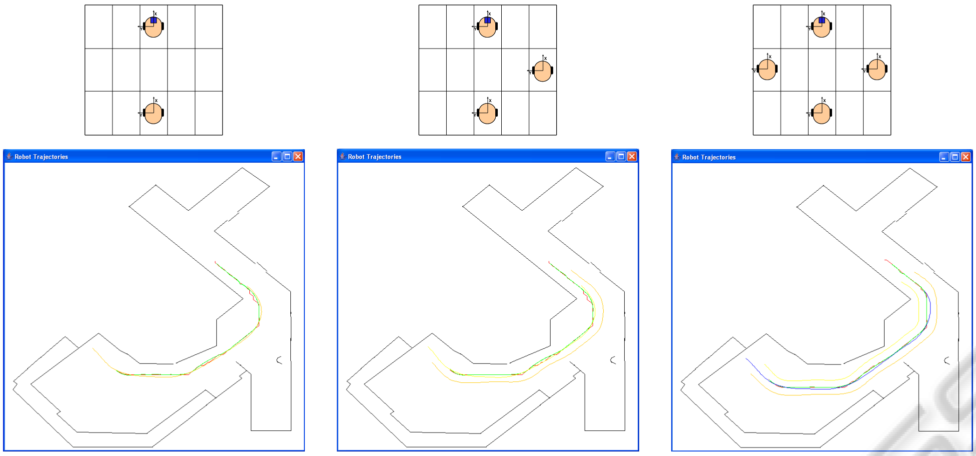

Figure 4: Results in simulation for formations with different number of robots.

and all the follower can follow the movements of the conductor by the utilization of virtual points.

4 CONCLUSIONS

The paper describes a new method for a team of heterogenous robots to navigate maintaining any type of formation by the introduction of "virtual points". In this application, the robots without sensory power get support for the navigation from the robot with navigation and localization facilities. In this way, all the robots are able to follow a predefined path getting help from others if necessary, that is, cooperating among them.

Results in simulation have demonstrated that the presented approach, where robots maintain the formation only using communication and odometry, is suitable for getting the maintenance of formations with any number of robots.

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