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Task Switching for Specialized Mobile Robots Working in Cooperative Formation

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***Abstract* – A formation transition strategy for a fleet of cooperative mobile robots is presented in this paper. Switching to a new formation in order to handle a specific task is controlled by subdividing the plane of movement into different zones with the assumption that each zone involves a specialized task to be performed by a specific agent. As such the robots adapt their formation as they hit a new zone, with the leader robot being assigned as the agent that best responds to the new zone task requirements. The proposed system is modeled using nonholonomic mobile robot dynamics. A kinematic and torque controller for nonholonomic mobile robots is presented to control path following and group formation. Collision avoidance is introduced using repulsive potential forces to prevent the agents from colliding during formation transition and to control inter-agents separation. To demonstrate the proposed system validity, simulation results are presented which show that the group of robots effectively coordinate themselves within each zone as a desired formation by selecting a new robot to be a leader while ensuring smooth switching to a new formation from zone to zone and without collisions.**

***Index Terms – Task Switching, Specialized agents, Cooperative Formation, Leader-Follower, Potential forces*.**

I. Introduction

Collaborative tasks can be achieved by multi-agent systems and find numerous applications as much in industry as in military. Over the last two decades cooperative formation control of multi-agent systems received significant attention from researchers. This research examines the design of a multi-agent system that involves specialized agents, that is a number of agents with different and specific capabilities. It extends the concept of cooperative formation and proposes a rigorous proccess taking into account such specialized agents, each one being suited to handle a specific task, here defined in accordance with the different zones of the movement plan. The proposed framework allows robots to smoothly and safely switch their position and change the overall formation based on the task to be handled in each zone. The paper defines how the formation is managed in each zone and how the switching happens from one zone to the other. Nonholonomic mobile robots are considered here and path following and group formation are controlled using a kinematic and torque controller. The collision avoidance control between agents is built using repulsive potential forces to prevent the agents from colliding and to preserve a specific inter-agent separation.

This paper is organized as follows: Section II provides a concise overview of prior cooperative formation techniques. The nonholonomic mobile robot model is presented in section III. In section IV a kinematic and torque controller is defined to control path following and group formation of the robots. The proposed task switching algorithm and the leader selection process are developed in section V where collision avoidance control is also presented. Finally, to demonstrate the system validity, simulation results are presented in section VI.

II. Cooperative Formation and Control: Prior Art

Earlier work on cooperative formation control introduced many strategies to address multi-agent system formation and control, including behavior-based approaches, potential fields, leader-follower formation, or generalized formation approaches. In terms of applications, in [1], a cooperative formation of multi-agents is proposed to transport an overweight object based on a pusher-puller formation. The cooperation between multiple robots and a human operator to carry out an inspection task is addressed in [2]. Moving target tracking with a group of mobile robots is developed in [3]. Parker [4] reports on several tasks that can be performed using multi-robot systems such as cooperative localization, mapping, exploration, formation control and object transportation.

Formation control can be achieved using a behavior-based approach, which means that the behavior of each agent in the group is designed such that the desirable group behavior emerges as a result [5]. In [6] various behaviors are analyzed where the sensory input is used to choose an appropriate behavior for each robot. Behavior-based formation approach is also adopted in [7] and a genetic algorithm is used to determine the behavior control parameters. A dynamic approach to behavior formation is addressed in [8], where formation control is modeled into nonlinear attractor dynamics.

Fierro *et al*. [9] consider the problem of leader-follower formation control as a model switching control system. In [10] a framework is implemented for leader-follower formation. A reactive tracking controller is proposed to make each follower maintain its desired position to its leader.

Finally, a formation approach is presented in [11]. Using generalized coordinates, the agent's location, ordination, and the group's shape are characterized with respect to a reference point based on generalized coordinates. In [12] and [13] the shape formation is also expressed in terms of generalized coordinates. The virtual structure formation approach is introduced in [14]. Based on virtual structure control the group of robots should maintain a rigid formation. The formation control of multi-agent systems is derived in [15] from general non-linear dynamics (servomechanism method). Alternatively, a switching algorithm is proposed in [16] that combines genetic based formation and reinforcement learning based obstacle avoidance.

III. System Modeling and Assumptions

A nonholonomic mobile robot model [17] with 2-dimensional coordinates space system (*n*=2) and subjected to *m* constraints is considered and can be described in global coordinates (*q*). The Euler Lagrange form of the model can be expressed as:

$$\mathrm{M}(q)\ddot{q} + V_m(q,\dot{q})\dot{q} + F(\dot{q}) + G(q) + \tau_d = B(q)\tau - A^T(q)\lambda \quad (1)$$

where $M(q) \in \mathcal{R}^{n\times n}$ is a symmetric positive definite inertia matrix; $V_m(q,\dot{q}) \in \mathcal{R}^{n\times n}$is a centripetal and coriolies matrix; $F(\dot{q}) \in \mathcal{R}^n$ denotes the surface friction; $G(q) \in \mathcal{R}^n$ refers to the gravitational vector and $\tau_d \in \mathcal{R}^n$ denotes unknown disturbance. $B(q) \in \mathcal{R}^{n\times r}$ is the input transformation matrix (r is the number of control signals); $\tau \in \mathcal{R}^r$ is the input vector; and $A^T(q) \in \mathcal{R}^{m\times n}$ is a matrix associated with constraints. Finally, $\lambda \in \mathcal{R}^m$ is a constraint forces vector. If we consider that all kinematic equality constraints are not time-dependent [17], it follows that:

$$A(q)\dot{q} = 0 \quad (2)$$

Let $S(q)$ be a full rank matrix of a set of smooth and linearly independent vector fields in the null space of $A(q)$, i.e:

$$S^T(q)A^T(q) = 0 \quad (3)$$

If we consider (2) and (3), it will be possible to find a vector time function $\mathrm{v}(t) \in \mathcal{R}^{n-m}$ such that:

$$\dot{q} = S(q)\mathrm{v(t)} \quad (4)$$

The position of the robot shown in Fig. 1 in an inertial Cartesian frame $\{\mathrm{O,X,Y}\}$ can be represented by the vector $q = [x, y, \theta]^T$. The motion kinematic relation, (4), can be represented in terms of translational, v , and angular, ω , velocities as:

$$S(q) = \begin{bmatrix} cos(\theta) & -d_r sin(\theta) \\ sin(\theta) & d_r cos(\theta) \\ 0 & 1 \end{bmatrix} \quad (5)$$

$$\mathrm{v} = \begin{bmatrix} v \\ \omega \end{bmatrix} \quad (6)$$

$$\dot{q} = \begin{bmatrix} \dot{x} \\ \dot{y} \\ \dot{\theta} \end{bmatrix} = \begin{bmatrix} cos(\theta) & -d_r sin(\theta) \\ sin(\theta) & d_r cos(\theta) \\ 0 & 1 \end{bmatrix} \begin{bmatrix} v \\ \omega \end{bmatrix} \quad (7)$$

where d_r is defined in Fig. 1.

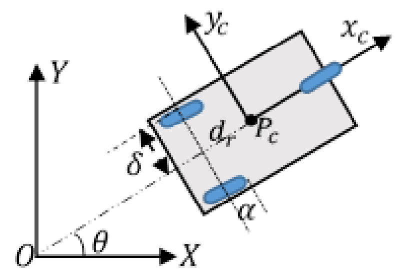

Figure 1. A nonholonomic mobile robot internal Cartesian frame.

The matrices that define the model dynamics based on Fig. 1 are expressed in (1) where,

$$M(q) = \begin{bmatrix} m & 0 & md_r sin(\theta) \\ 0 & m & -md_r cos(\theta) \\ md_r sin(\theta) & -md_r\, cos(\theta) & I \end{bmatrix} \quad (8)$$

$$V_m(q,\dot{q}) = \begin{bmatrix} -md_r\dot{\theta}^2 cos(\theta) \\ -md_r\dot{\theta}^2 sin(\theta) \\ 0 \end{bmatrix} \quad (9)$$

$$G(q) = 0 \quad (10)$$

$$B(q) = \frac{1}{\alpha}\begin{bmatrix} cos(\theta) & cos(\theta) \\ sin(\theta) & sin(\theta) \\ \delta & -\delta \end{bmatrix} \quad (11)$$

$$\tau = \begin{bmatrix} \tau_1 \\ \tau_2 \end{bmatrix} \quad (12)$$

The system represented by (1) can be transformed to be more appropriate for control consideration. Equation (4) can be differentiated to obtain $\ddot{q}$ and substituted into equation (1), then multiplying the resulting equation by S^T. The final motion equations of the nonholonomic mobile robot will be given as in [17]:

$$\dot{q} = S\mathrm{v} \quad (13)$$

$$S^T MS\dot{\mathrm{v}} + S^T(M\dot{S} + V_m S)\mathrm{v} + \bar{F} + \bar{\tau}_d = S^T B\tau \quad (14)$$

where $\mathrm{v}(t) \in \mathcal{R}^{n-m}$ is a vector of the velocities. Equation (14) will be rewritten as:

$$\bar{M}(q)\dot{\mathrm{v}} + \bar{V}_m(q,\dot{q})\mathrm{v} + \bar{F}(\mathrm{v}) + \bar{\tau}_d = \bar{B}\tau \quad (15)$$

$$\bar{\tau} = \bar{B}\tau \quad (16)$$

where $\bar{M}(q) \in \mathcal{R}^{r\times r}$ is a symmetric positive definite inertia matrix; $\bar{V}_m(q,\dot{q}) \in \mathcal{R}^{r\times 1}$ is the centripetal and coriolies matrix; $\bar{F}(v) \in \mathcal{R}^{r\times 1}$ is the surface friction; $\bar{\tau}_d$ refers to unknown disturbance and $\bar{\tau} \in \mathcal{R}^{r\times 1}$ is the input vector.

Equation (15) describes the system behavior in the vehicle coordinates frame. This means that $S(q)$ is the transformation matrix which transforms the velocities of the vehicle coordinates 'v' to Cartesian coordinates velocities, $\dot{q}$.

Finally, the i^{th} robot system should satisfy the following assumptions [17]:

1. *Boundedness*: $\bar{M}_i(q)$, the norm of $\bar{V}_{m_i}(q,\dot{q})$, and $\bar{\tau}_d$ are bounded.
2. *Skew Symmetric*: The matrix $\bar{M}_i(q) - 2\bar{V}_{m_i}(q,\dot{q})$ is skew symmetric such that: $x^T\left(\bar{M}_i(q) - 2\bar{V}_{m_i}(q,\dot{q})\right)x = 0$.

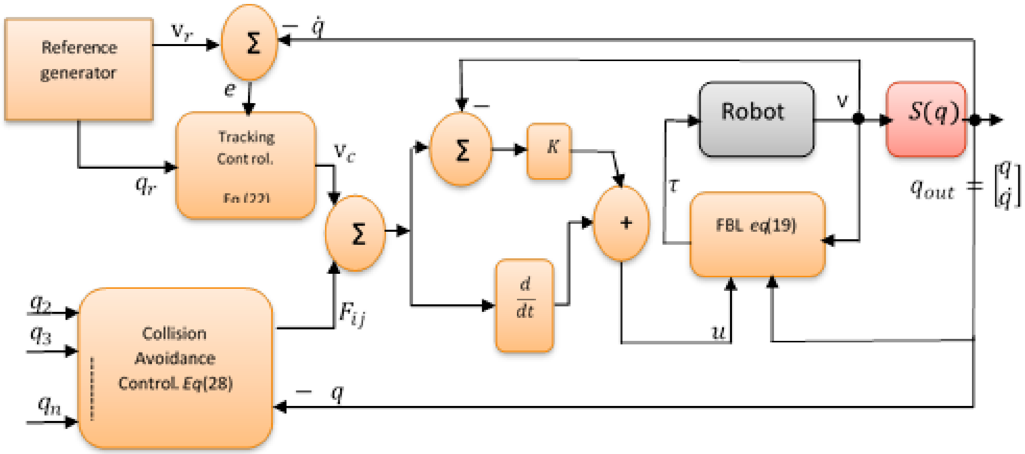

Figure 2. Schematic diagram of the proposed formation controller.

IV. Control Design

The proposed system combines two cascaded stages. The first stage controls the robot dynamics system and the second one controls the formation. The schematic structure of the proposed system is presented in Figure 2.

A. Dynamics Control

A method for controlling the dynamics nonlinearities of the nonholonomic mobile robot is implemented based on the output feedback. In particular, feedback linearization is used to cancel the nonlinear part of the vehicles dynamics. The resulting system is an adequate linearized system for both navigation and group formation. With the assumption that when the surface friction $\bar{F}(\mathrm{v}) = 0$, and the unknown disturbance $\bar{\tau}_d = 0$, the robot dynamics can be linearized as follows :

$$\dot{\mathrm{v}} = \bar{M}^{-1}(-\bar{V}_m(q,\dot{q})\mathrm{v} + \bar{B}\tau) \tag{17}$$

$$\dot{\mathrm{v}} = -\bar{M}^{-1}\bar{V}_m(q,\dot{q})\mathrm{v} + \bar{M}^{-1}\bar{B}\tau \tag{18}$$

Then using feedback linearization (FBL), one can choose the input torque τ to be:

$$\tau = (\bar{M}^{-1}\bar{B})^{-1}(u_i + \bar{M}^{-1}\bar{V}_m(q,\dot{q})\mathrm{v}) \tag{19}$$

where u_i is the proposed control signal which controls the whole system dynamics behavior in the vehicle local frame, as shown in Fig. 2. Substituting (19) in (18) leads to

$$\dot{\mathrm{v}} = u_i \tag{20}$$

This means that the translational and the angular velocity of the robot can be controlled directly by the proposed control signal u_i. The $\dot{\mathrm{v}}$ dynamic in (20) is in the robot body frame's representation (i.e. its local frame).

B. Feedback Acceleration Control

Next, the control signal $\mathrm{v}(t)$ will be converted to torque control $u(t)$ in (19) for the actual physical agent. For that purpose, (20) satisfies the desired behavior such that the deriving velocity $\mathrm{v}(t)$ can be converted to a control signal (input torque).

For the system to track a reference trajectory resulting from path planning it is assumed a full knowledge of the system dynamics is available. Therefore (19) can be used to calculate the input torque $\tau(t)$ from a given control signal $u(t)$, which means that the control signals $u(t)$ and $\tau(t)$ can be derived from a control signal $\mathrm{v_c}(t)$ in order to control the linearized steering system (20). In this control design, backstepping control [17] is used.

$$u_i = \dot{\mathrm{v}}_c + K(\mathrm{v_c} - \mathrm{v}) \tag{21}$$

where K is a positive definite diagonal matrix and

$$\mathrm{v}_c = \begin{bmatrix} \mathrm{v}_r \cos e_3 + k_1 e_1 \\ \omega_r + k_2 \mathrm{v}_r e_2 + k_3 \mathrm{v}_r sin\ e_3 \end{bmatrix}; \mathrm{v}_r = [v_r\ \omega_r]^T$$

$$q_r = [x_r\ y_r\ \theta_r]^T \tag{22}$$

with

$$\begin{bmatrix} e_1 \\ e_2 \\ e_3 \end{bmatrix} = \begin{bmatrix} cos\theta & sin\theta & 0 \\ -sin\theta & cos\theta & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} x_r - x \\ y_r - y \\ \theta_r - \theta \end{bmatrix}$$

and v_r is the reference velocity, q_r is a given arbitrary configuration, and e is the tracking error.

V. Switching and Reformation

The proposed switching strategy is based on the assumption that specialized zones of operation can be defined to subdivide the mobile robot workspace and be interconnected in a way that the robots can change their formation when transferring from zone to zone. This formulation generalizes the definition of specialized tasks associated with various parts of an operation to which specific agents, or robots, would be assigned based on their on-board sensing or tooling devices. In this context, the switching and formation problem is solved as follows:

A. Formation Control

The group formation is monitored with respect to a global reference in order to create a global representation of the formation and to preserve a stable formation with all robots until the group hits the next zone and must transition to a new specialized agent (robot) to become the leader. At that point the system switches to a new formation.

B. Local to Global Frame Pose Conversion

The pose of the robot is initially referenced to its local frame and then transformed from its local frame to the global formation frame, as follows:

$$P_{global} = RP_{loc} + P_{ref} \tag{23}$$

where P_{loc} is the robot pose in its local frame, P_{ref} defines the local reference frame in the global frame and P_{global} denotes the updated pose in the global frame with:

$$R = \begin{bmatrix} \cos(\theta ref) & -\sin(\theta ref) & 0 \\ \sin(\theta ref) & \cos(\theta ref) & 0 \\ 0 & 0 & 1 \end{bmatrix}; P_{loc} = \begin{bmatrix} x_l \\ y_l \\ \theta_l \end{bmatrix}; P_{ref} = \begin{bmatrix} x_{ref} \\ y_{ref} \\ \theta_{ref} \end{bmatrix}$$

While the robots are moving the angles of reference are changing based on the predefined trajectory. For stable reference following and proper fleet formation, each robot is required to update its new global heading angle based on the direction of the movement. The *updated heading angle* of the robot is obtained using the differences in x and y between their current (x_i, y_i) and previous positions (x_{i-1}, y_{i-1})

$$\theta_{updated} = atan2((y_i - y_{i-1}), (x_i - x_{i-1})) \tag{24}$$

Based on the updated value of the heading angle of the robot in the global formation frame the corresponding translational and angular velocities, (v, ω), of the nonholonomic mobile robot defined in (6) must be updated, as follows:

$$\dot{q} = S\mathrm{v} \tag{25}$$

where

$$\dot{q} = \begin{bmatrix} \dot{x} \\ \dot{y} \\ \dot{\theta} \end{bmatrix}; S = \begin{bmatrix} cos\theta_{updated} & -dsin\theta_{updated} & 0 \\ sin\theta_{updated} & dcos\theta_{updated} & 0 \\ 0 & 0 & 1 \end{bmatrix}; \mathrm{v} = \begin{bmatrix} v_x \\ v_y \\ \omega \end{bmatrix}$$

$$\mathrm{v} = \frac{\dot{q}}{S} = S^{-1}\dot{q}$$

$$\begin{bmatrix} v_{updated} \\ \omega_{updated} \end{bmatrix} = S^{-1}\dot{q} \tag{26}$$

C. Switching to New Zone Formation

The procedure for switching to a new formation is implemented based on subdividing the planar workspace in several zones. The robots are associated each to one zone, such that each zone requires a different formation. This concept can be used to rearrange the positions of the robots based on their specialty or zone requirement to handle and execute a specified task. When the group of robots hits a new zone in the subdivided workspace, the corresponding specific task is associated with a given robot from the formation, which becomes the group leader while the formation remains within that zone. For example, if robot 1 is assigned to be the leader in zone 1 and robot 2 is assigned to be the leader in zone 2, the proposed control system manages the cooperative formation and determines how the group leader is changed automatically from one zone to the other. The proposed framework includes a number of specific procedures:

1) Zone Definition

With no loss of generality, the zones are predefined as rectangular sectors with different widths and lengths. In a sample case, zone parameters are defined as shown in Fig. 3. The pose is the (x, y) coordinates of the lower left corner point of the zone. The dimensions along the x axis and the y axis are also considered.

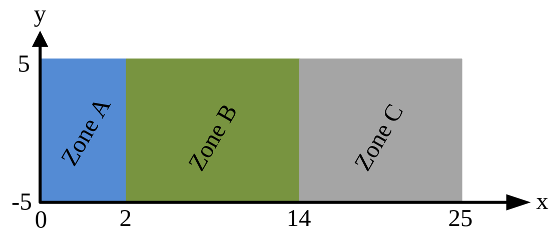

Figure 3. Example of zones subdivision

2) Zone Detection

The robots detect their zone by calculating the center point of their formation. Then this point is checked against the subdivisions of the workspace to determine in which zone the group of robots is located. The central position of the formation is calculated by averaging of all of the robots positions $p_i \in \mathcal{R}^2, i = 1, \dots, a$, where a is the total number of robots, or agents.

$$p_{center} = \frac{\sum_0^a p_i}{a} \tag{27}$$

3) Zone based switching formation

When the center point p_{center} hits a new zone the robots positions are changed such that the references of the previous and new leader are exchanged and the robots are re-organized into a new formation centered around a new leader, who is specialized for the task at hand in the zone where the formation just entered.

4) Assigning a specific leader for each zone

When the group of robots hits a new zone, the first step is to determine which robot should become the leader in that new zone. The proposed leader changing approach is summarized in Fig. 4 and the switching and re-formation algorithm for each robot is further detailed in pseudo-code in Table 1.

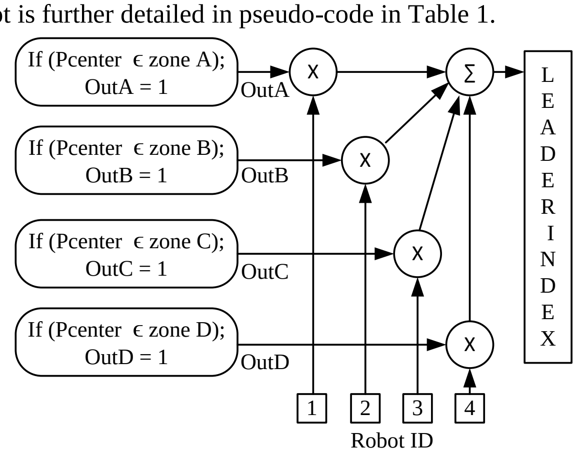

Figure 4. Leader index selection.

It relies on the assumption that a new leader index is selected as soon as any of the robots in the formation exits the current zone, that is any of the *Out* signals defined in Table 1 transitions to 0. For example, when the first robot passes from zone A to B, as shown in Fig. 3, it will lead to $OutA = 0$, and $OutB = 1$, and the new leader for zone B is identified.

TABLE 1: SWITCHING AND RE-FORMATION ALGORITHM.

Step1: $Compute\ the\ center\ point\ P_{center} = (x, y);$
Step2: $The\ lower\ left\ corner\ point\ in\ zone = (zoneX, zoneY);$
$The\ length\ of\ the\ zone\ on\ x\ axis = dimX;$
$The\ length\ of\ the\ zone\ on\ y\ axis = dimY;$
$if(x < zoneX\ ||\ x > zoneX + dimX);$
$\quad Out = 0;$
$elseif(y < zoneY\ ||\ y > zoneY + dimY);$
$\quad Out = 0;$
$else\quad Out = 1;$
Step3:
$If\ Out = 0\ change\ the\ formation\ to\ the\ new\ zone$
$\quad elseif\ Out = 1$
$\qquad keep\ the\ same\ formation, move, and\ repeat\ steps\ 1\ \&\ 2;$

D. Inter-Agent Collision Avoidance

In order to achieve the ability to navigate safely and switching to a new formation without any inter-agent collisions, a potential field based control technique is developed to generate internal repulsive forces between the robots [18]. The collision avoidance and the formation control algorithms work together to keep the agent in a collision-free formation during transitions while also preserving a predefined separation in between the robots as they navigate. The repulsive potential force between each two neighboring agents i, j can be expressed as:

$$F_{rep_{ij}} = -\nabla_{P_i} \mathrm{V}_{ij}(P_i, P_j) \tag{28}$$

$$\nabla_{P_i} = \frac{\partial}{\partial P_i},\ P_i = [x_i, y_i]^T,\ P_j = [x_j, y_j]^T \tag{29}$$

Define: $\vec{R}_{ij}(t)$ as the vector relating the Euclidean distance between agents i and j with $\|\vec{R}_{ij}\| = R_{ij}$, we have $R_{ij} = -R_{ji}$. Let, $R_{ij}(t) = \|P_i(t) - P_j(t)\|, i = 1,2, \ldots\ldots, N. j = 1, 2, \ldots, N.$

$$\mathrm{V}_{ij} = \begin{cases} \frac{1}{2} K_a (R_{ij} - L)^2, & R_{ij} \le L \\ 0, & Otherwise. \end{cases} \tag{30}$$

where L is the minimum desired separation between each two agents and V_{ij} is continuously differentiable. If $R_{ij} < L$ this potential produces a repulsive force, and it will produce a null force if $R_{ij} \ge L$. Now suppose that:

$$R_{ij} = \sqrt{\left(P_i(t) - P_j(t)\right)^T \left(P_j(t) - P_i(t)\right)},\ R_{ji} = \sqrt{\left(P_j(t) - P_i(t)\right)^T \left(P_i(t) - P_j(t)\right)}$$

$$\frac{\partial R_{ij}}{\partial (P_i, P_j)} = \left[\frac{1}{R_{ij}}\left(P_i(t) - P_j(t)\right)^T + \frac{1}{R_{ji}}\left(P_j(t) - P_i(t)\right)^T\right] \tag{31}$$

$$\frac{\partial \mathrm{V}_{ij}}{\partial R_{ij}} = K_a\left(R_{ij} - L\right) \tag{32}$$

using the chain rule we get:

$$\frac{\partial \mathrm{V}_{ij}}{\partial (P_i, P_j)} = \frac{\partial \mathrm{V}_{ij}}{\partial R_{ij}} \frac{\partial R_{ij}}{\partial (P_i, P_j)} \tag{33}$$

substituting (31), (32) in (33) leads to the inter-agent repulsive potential to be given by

$$F_{rep_{ij}} = -K_a\left(R_{ij} - L\right)\frac{1}{R_{ij}}\left[\left(P_i(t) - P_j(t)\right)^T - \left(P_j(t) - P_i(t)\right)^T\right] \tag{34}$$

Then u_i in (21) will change as defined in Fig. 2 to

$$u_i = \dot{\mathrm{v}}_c + \dot{F}_{rep_{ij}} + K(\mathrm{v}_c + F_{rep_{ij}} - \mathrm{v}) \tag{35}$$

VI. SIMULATION RESULTS

In order to validate the proposed robots formation control framework, a group of mobile robots was simulated such that they operate cooperatively and follow global references using a backstepping nonlinear control scheme. The robots preserve a stable formation until the group hits the transition with a new zone in their workspace. Then the zone detection and leader selection (task switching) procedures defined in section V.C manage the change of group leader to a new specialized agent. At that point, the system switches to a new formation and the agents are re-organized. Both during the transition and while navigating through a given zone, the group navigates safely and keeps enough inter-agent separation to avoid collisions between the agents using repulsive potential fields. The proposed system is designed and simulated in MATLAB. The robot parameters used in this study as indicated in Fig. 1 are $m = 10kg, \alpha = 0.05\ m, \delta = 0.5\ m, I = 5kg\text{-}m^2; d_r = 0.8$. Fig. 5a shows the initial conditions of the group formation in a sample simulation case. The red trajectory represents the group leader trajectory in a given zone A. At the moment when the center of the formation enters in zone B, the group's leader (red) hits the point (2,0) as shown in Fig. 5a. Then the system switches automatically to the relevant specialized robot (green) to be the group's leader in zone B. Fig. 5a also indicates that the green robot started to switch to become the leader in zone B while it was at coordinates (0.5, 2). Fig. 5b shows the re-formation process taking place in zone B (with the new leading robot having the green trajectory). Fig. 5c presents the trajectories of the whole group navigation in zone B and how the system eventually switches to select the 3rd robot (pink) to become the group leader in zone C. The minimum distance desired between the green and the pink robots is achieved and the repulsive force operates, ensuring that the pink robot passes the cross point at a given instant while the green one passes a little later.

VII. CONCLUSION AND FUTURE WORK

This work presents the design and implementation of a task switching and cooperative formation framework for specialized mobile agents. The proposed system assigns the task to a specific agent depending on the position of the formation and the task is executed by a different robot in each zone. A dynamical model of nonholonomic mobile robots is considered whereas a kinematic and torque controller is used to control path following and group formation. To assure a safe navigation and smooth task switching without any inter-agent collisions, a potential field layer is integrated which generates internal repulsive forces between the robots. The collision avoidance and the formation control algorithms work together to keep the agents far enough from each other while managing transition in the group leader as zones requiring the intervention of a given specialized agent are accessed by the formation. The efficiency of the proposed system was validated via simulations of numerous environments on MATLAB. In future work, the system will be implemented experimentally on real robots.

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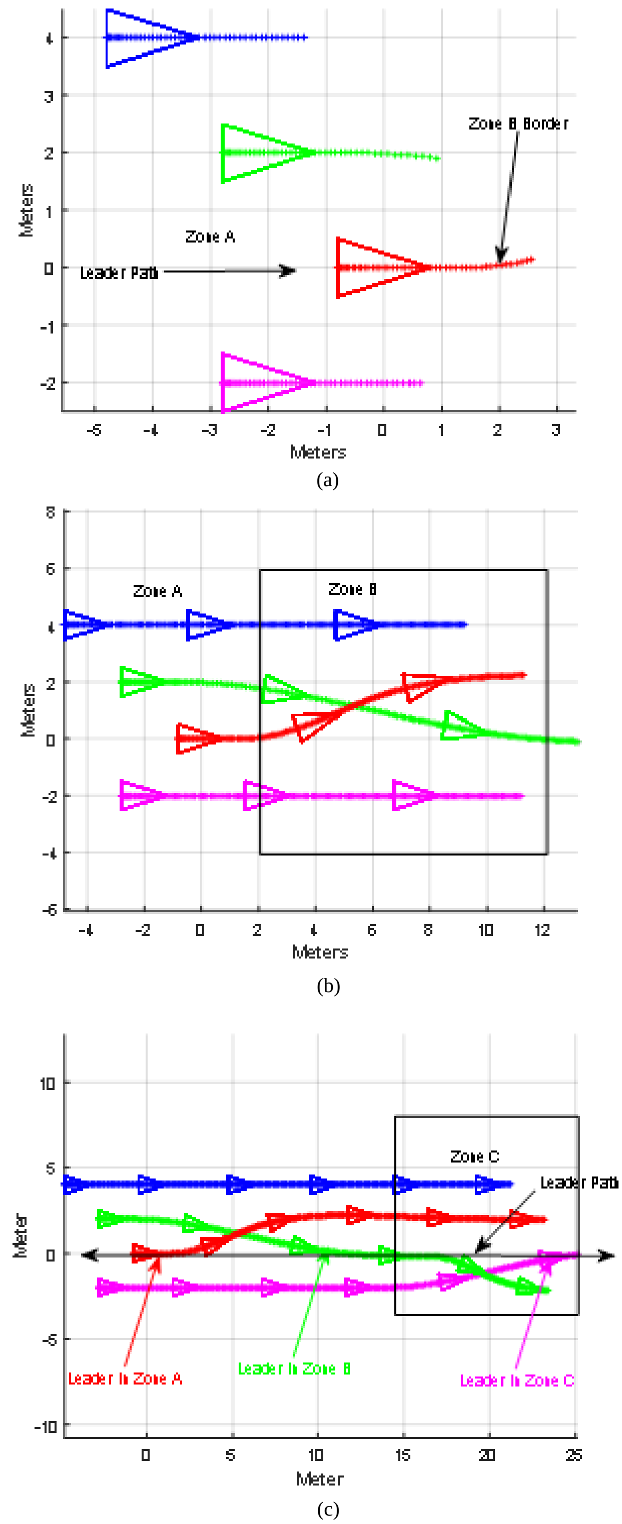

Figure 5. Group formation and switching control response.