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Scalable multi-agent formation with bearing only measurement: Consensus based approach

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ABSTRACT

Target centric deviated cyclic pursuit is a variant of the deviated cyclic pursuit strategy designed to track a target. Deviated cyclic pursuit has more flexibility as compared to the classical cyclic pursuit laws. In this work, we obtain a scalable formation of the UAVs around the target. The formation is scaled in a decentralized manner by changing a parameter of any of the vehicles. The strategy uses only bearing angle information of the target and the neighbours. We carried out the analysis assuming simple kinematic model for each vehicle. At equilibrium, the vehicles get into a rigid polygonal formation which rotates around the target. The size of the polygon is scalable. We analysed the local stability of equilibrium formations. Simulation results are presented to demonstrate effectiveness of the proposed strategy. The strategy is applied to miniature areal vehicles (MAV) represented by 6-DOF dynamics in a hardware in-loop simulator, which includes all on-board electronics of the MAVs.

1. Introduction

Several applications such as convoy protection, natural resource monitoring, geographical exploration, etc. require persistent monitoring of a point of interest from multiple directions. A cooperating team of multiple autonomous vehicles can be used for such tasks as they offer several advantages such as reliability, robustness, scalability and better efficiency. In this paper we propose a control strategy for multiple autonomous vehicles which makes them move from any initial position towards a specific target, and upon reaching the target they continue to move around it with uniform distribution. Moreover, the distance to the target can be easily controlled in a decentralized manner.

Decentralized target tracking using multiple vehicles has been studied extensive in the literature ([18,9,13,2,12,22,17] to list a few). Some of the recent works include [21,5,27,28]. The authors in [21] proposed a strategy based on model predictive control with moving horizon estimation to track a moving target with two UAVs. In [5], a variant of the cyclic pursuit strategy is used to monitor a stationary target with a group of unicycles. In [27], authors considered nonholonomic vehicles and control both the linear and angular velocities of the vehicles. At equilibrium, the vehicles get distributed uniformly as they move on concentric circles about a stationary target. Ring topology is assumed and the vehicles use full information about their neighbours and the target. In [28], the authors developed a control strategy to enclose a stationary target using a single and a group of unicycles. The unicycles use only the bearing information of the target and their neighbours in order to maintain a circular formation of a pre-specified radius about the target. The essence of the control strategy presented in this paper is similar to that presented in [28,21,5]. However, our strategy also achieves scalable formation.

Formation scaling and reconfiguration is an interesting problem and often very useful in many applications. It has attracted increasing research attention in the recent years. However, not much work on distributed reconfiguration of formation has been reported in the literature. There are three kinds of approaches for formation scaling – relative position based, distance based, and bearing-angle based approaches. The papers [3,4] discuss about scaling the formation of a group of agents. The authors have assumed linear model of the agents. The agents move in formation and the scaling of the formation happens automatically with the relative position feedback. In [19], the formation of a group of linear agents is achieved using distance based information. A acyclic graph is considered and the formation is scaled by changing the relative position of the leader with respect to the first follower. Bearing only information based scaling of multi-agent formation is studied in [26]. The formation is specified in terms of the inter-neighbour bearing angles. At least two leaders are required to control the centre and the size of the formation.

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Formation reconfiguration is studied in [25,8]. In [25], reconfiguration of a group of satellite is achieved using cooperative control. The authors in [8] demonstrate reconfiguration between longitudinal and circular formation of UAVs. In this paper, we propose a scalable circular formation about the target using deviated cyclic pursuit. Deviated cyclic pursuit has been studied in [16]. The authors achieve rendezvous of the agents which are modelled by linear kinematics. In [20], a variation of the cyclic pursuit is used. Deviated cyclic pursuit can be considered as a spacial case of these variations. Agents with linear kinematics are considered and they achieve rendezvous or circular or spiral motion depending on the controller parameter. However, to the best of the authors knowledge, decentralized formation scaling of unicycles for target tracking applications have not been studied.

In this paper, we propose a deviated cyclic pursuit strategy for target tracking applications. The strategy produces a scalable multi-agent formation for efficiently monitoring a target. We considered a group of UAVs which are modelled as unicycles. The UAVs get into a fixed polygonal structure that rotates around the target. The polygon is regular in shape which ensures uniform distribution of the UAVs around the target. Deviated cyclic pursuit provides the flexibility to scale the polygonal structure, thereby resulting in increasing or decreasing the distance of the UAVs from the target. This scaling can be achieved in a decentralized manner by changing a parameter of only one agent, which can be chosen randomly. This parameter is called the deviation angle. It might seem that this strategy is similar to the leader–follower cases [10]. However, here we do not have any fixed leader and any one of the vehicles can be chosen to change the deviation angle. The motivation of this work stems from the requirement to scale a formation of a large number of agents in a decentralized way. We also achieve the scaling of the formation with only bearing angle information. In [28], bearing angle information is used for a circular formation of unicycles. However, formation scaling is not addressed. The primary contributions of this work are as follows:

- A simple heading control law based on bearing angle information only,
- Scaling the formation by manipulating a parameter of any one of the vehicles,
- Verifying the strategy on 6DOF model in hardware-in-loop simulator.

The preliminary results are presented in [14]. We have studied those results in more details in this paper and also analysed the local stability of the system.

The paper is organized as follows. The system model with the proposed control law is presented in Section 2. In Section 3 possible equilibrium formations are discussed. In Section 4, local stability analysis is carried out. Section 5 gives the realistic MAV model and discusses the details of implementation of this strategy on hardware-in-loop simulator. Simulation results are presented in Section 6. Section 7 concludes the paper.

2. Problem formulation

Cyclic pursuit is a simple strategy derived from the behaviour of social insects. Given a set of n agents that are numbered from 1 to n, each agent i pursues the next agent $i+1 \pmod n$. This generates different types of formations depending on the model of each agent and the way each agent follows the next one. This strategy and its applications have been discussed in great detail in [15,24,20,7]. In this paper, the strategy has been modified to track a target point with a group of n unicycle agents. The kinematics of each agent i is

$$\dot{z}_x^i = V_i \cos(h_i), \quad \dot{z}_y^i = V_i \sin(h_i), \quad \dot{h}_i = u_i \tag{1}$$

where $P_i = [z_x^i, z_y^i]^T$ represents the position and h_i represents the heading angle of the agent i. V_i and u_i represent the linear speed and angular speed of agent i respectively. We assume that the agent i is moving with constant linear speed, that is, V_i is constant and the motion of the agent i is controlled using the angular speed, u_i.

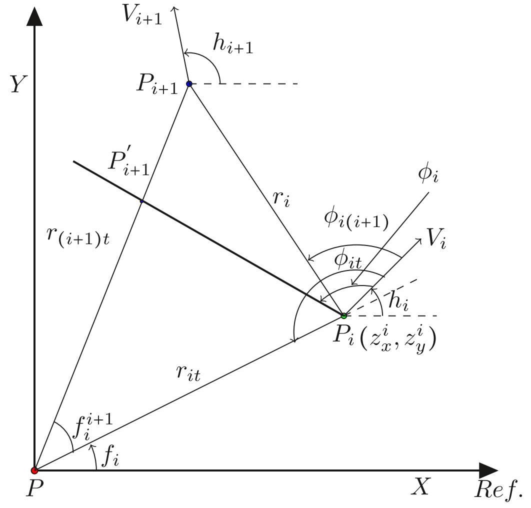

Fig. 1. Positions of the vehicles in a target centric frame.

We start with the assumption that all the agents can see the target during their entire manoeuver. But later we show that it can be relaxed and the minimum requirement is that the target is in the field of view of at least one agent. The strategy demands only bearing angle information which can be acquired easily with sensors like the vision sensors.

Consider Fig. 1. Point P represents the target position. Assume a target centric reference frame. Agents i and $i+1$ are located at P_i and P_{i+1} respectively. The variables in Fig. 1 are as follows:

r_{it}	distance between ith agent and the target,
r_i	distance between ith agent and $i+1$ th agent,
f_i	angle made by the vector r_{it} with respect to the reference,
f_i^{i+1}	angular separation between agent i and agent $i+1$ taken with respect to target,
ϕ_{it}	bearing angle of agent i with respect to the target,
$\phi_{i(i+1)}$	bearing angle of agent i with respect to agent $i+1 \pmod n$,
h_i	heading of agent i with respect to the reference.

We modify the classical cyclic pursuit law [15] for target enclosing problem. In classical cyclic pursuit, the agent i, positioned at P_i, follows $i+1$ th agent at P_{i+1}. In this paper, the agent i also follows the target at P. Let ρ_i be a constant which decides the weight agent i gives to the target information over the information of the agent $i+1$. We call this parameter the *pursuit gain*. The parameter ρ_i can take values between 0 and 1. This weighing scheme is mathematically equivalent to following a virtual leader along the line $P_iP'_{i+1}$ with bearing angle ϕ_i, which is calculated as

$$\phi_i = (1-\rho_i)\phi_{it} + \rho_i \phi_{i(i+1)}. \tag{2}$$

We introduce a new angle δ_i that adds an offset to the line $P_iP'_{i+1}$. We call this angle as deviation angle. The deviation angle gives the flavour of deviated pursuit in the cyclic pursuit strategy. It gives