Distributed Non-linear Flocking Control of Mobile Robots

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Abstract— **This proposal suggests outline of research project for EE505 course in Spring 2017. The subject is distributed control of a group of wheeled mobile robot. The main goal of control design is achieving approach to make those robot move in a group with harmony. To be more specific, the goals of flocking control consist of collision avoidance, same heading angle, unanimity speed and obstacle avoidance. here, we first review the flocking control concept. Then we briefly introduce non-holonomic non-linear mechanical system. Afterwards we review some recent work on Flocking Control of non-holonomic mechanical system. The main contribution of this research is expanding lyapunov based control scheme for distributed flocking control of non-holonomic mobile robot considering obstacle avoidance that will be discussed in second section of this proposal.**

Keywords: Non-holonomic system, Lyapunov function, Flocking control, Graph theory, Distributed Control

I. INTRODUCTION AND MOTIVATION

Flock motion is one of the most elegant phenomena in nature, where the same simple behavior of many autonomous individuals leads to complex motion patterns. Flocking has many benefits for in natural systems, to enumerate some of which, we can recognize 1) more efficient when dealing with foraging or navigational tasks; 2) redundancy and system's parallel processing nature leads to fulfilling goal of the system; 3) more alert regarding to environmental condition and defense against threats [1]. The ability of such natural system motivate researcher to inspire from natural systems and deploy flock in artificial agents with distributed control. Flocking control can be really useful for many area such as automatic vehicle transportation and autonomous rescue robots. Three heuristic rules that led to creation of the first artificial of flocking can be summarized as follow [2]:

1) Flock Centering: attempt to stay close to nearby flockmates; 2) Collision Avoidance: avoid collisions with nearby flockmates; 3) Velocity Matching: attempt to match velocity with nearby flockmates 4) Obstacle Avoidance: avoid collision with stationary or moving barriers

Many studies have concerned flocking control to multiple agents. Nonetheless, a number of research that consider non-holonomic constraint on dynamic of agents is only small portion of whole literature. "A non-holonomic system in physics and mathematics is a system whose state depends on the path taken in order to achieve it" To put it in other words, the states cannot change arbitrary and some constraint must be met in order to reach the wanted states. Many mechanical systems have these constraints. For instance, automobile, mobile robot, UAVs and $\cdots$.

Non-holonomic behavior in robotic systems is interesting since it leads to the fact that the mechanism can be completely controlled with a reduced number of actuators. What's more, both planning and control are much more difficult in non-holonomic system compared to conventional holonomic systems, and require special techniques [3].

In this research we concern about flocking problem for non-holonomic wheeled mobile robot. Therefore, each agent has non-holonomic non-linear model with two control input. The kinematic model for wheeled mobile robot is used from [4].

Another facet of our research is that we are interested in distributed control scheme. Distributed control scheme is easy to implement and it only need information from neighbor agents. On contrary, in centralized control system, we need to communicate all information to leader agent. Therefore, centralized methods are not scalable because the communication and computational load grow with more number of agents. Nonetheless, there is no leader agent in decentralized control and each agent control itself by data obtained from neighbor agents.

Many works on trying to deal with distributed control of flocking control by by taking advantages of graph theory and network dynamic [5], [6]. Here, we review some of which that are related to non-holonomic agents flocking control.

In [7] A flocking protocol which is based on the neighborhood information of mobile robots is constructed based on distributed control. For convergence and collision avoidance analysis, a Lyapunov function is introduced. Also graph theory is employed to deal with distributed and network nature of the problem. Also this paper tries to keep control input bounded using BarBalat's lemma. However, this work does not address obstacle avoidance.

Also [8] develops the collective motion of flocking of networked mobile robots with non-holonomic model via proximity graphs. A potential function is suggested for distributed control based on neighbor information.

One different between [7] and [8] is that [8] considers a distributed control protocol for multi-flocking problem of networked mobile robots using potential function. So there is more than one flock. In [8], by combing algebraic graph theory with Barbalat's lemma, the control law guarantees the same velocity and heading angle for each sub-flock as well as collision avoidance of the whole system. Furthermore, the interaction topology of information exchange among the robots is time-varying. therefore, [8] deploys the proximity graphs to mathematically handle the problem of limited time-

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varying communication topology among robots.

[9] use the neighbors information for a distributed flocking algorithm on the basis of the combination of consensus and attraction-repulsion functions. Also arbitrarily shaped formation control problem of multi-agent system is solved by adding the information of the desired formation topology to the potential functions of the proposed flocking algorithm. Consider that the initial communication topology of the system is an undirected connected graph, the stability of the closed-loop system is proved by applying LaSalle-Krasovskii invariance principle. The connectivity of the communication network is preserved throughout the evolution by means of the effect of the potential functions. [9] considers collision avoidance, heading alignment and consensus in transitional and rotational speeds.

[10] deploys graph theory to investigate how a group of robots can follow a target robot that called leader while keeping predefined configuration. [10] consider two case with stationary and moving leader robot (that basically plays the role of a moving target). It presents a nonlinear proportional-integral (PI) based controller to actuate the followers.

In [11] again uses algebraic graph theory and Lyapunov analysis to guarantee the convergence by distributed control scheme. It uses discontinuous time invariant feedback control strategy to drives the multi-agent system to the desired formation configuration in the case of formation feasibility. Also it discussed the case in which formation is infeasible. However, this paper does not consider collision and obstacle avoidance.

The authors of [11] in [12] extent their results to meet collision avoidance criteria. Also it re-state formation infeasibility as previous work by considering collision avoidance. To be more specific, in [11] the decentralization level of the collision avoidance objective was limited by the fact that agents had to have knowledge of the exact number of agents in the group. However, in [12] the problem is treated in totally distributed manner.

[13] designed two method for converging multiple non-holonomic agent to stationary point and also a target point. In both cases, [13] consider delay in communication. It determines control laws for each agent using σ-processes and graph theory. [13] claims that it is the first paper that consider the issue of the cooperative control problem for general non-holonomic agents with limited communication capabilities among neighbors. It examined the proposed method on wheeled mobile robot.

As we review some recent works, to best of my knowledge, there is no work that considers obstacle avoidance with Lyapunov based distributed control scheme for non-holonomic system. [14], [15] have expanded some results for distributed Lyapunov based control considering obstacle avoidance; nevertheless, the agent's dynamic is not non-holonomic on those works. By the same token, [16] provides algorithm for flocking of non-holonomic mobile robot. The proposed method in [16] fulfill trajectory tracking, collision and obstacle avoidance, and reaching the goal in cohesion by flocking; however, this method is centralized one in which all agents' information is available for for one center control unit that coordinate agents movement. As discussed before, we are interested in distributed control scheme where all agents work independently from other agent and with communication only with neighbors. Therefore, a gap in the literature might be a lyapunov based distributed flocking control of non-holonomic agents with considering obstacle avoidance.

Last but not least, It should be mentioned that in many works, the analytical proof of convergence are not provided and they focus on simulation and hardware implementation to validate the credence of their proposed methods [1], [17].

II. Main Contribution and Project outline

For this project, I decided to start of with simulating the results in [7]. I think it is a good start for me because [7] uses Lyapunov function for convergences analysis with is close to the stuff we are learning on EE505 class. What's more, graph theory concepts are utilized to achieve distributed control scheme. Although my current research under Dr. Roy supervisory has noting to do with non-linear systems, I can probably take advantages of my current research on Network control system using graph properties.

Therefore, I will start by simulating results in [7]. Afterwards, I want to focus on expanding the Lyapunov function to capture obstacle avoidance since [7] does not consider it. I think it would be wonderful if I be able to extent the Lyapunov function to see obstacle avoidance issue. Probably it can be achieve if we consider obstacle as an additional node in graph which corresponds agent has no control input. Therefore, I will try to expand converges analytical results using Lyapunov in distributed sense considering obstacle avoidance. As it was mentioned in section 1, I have not seen any work on literature that focus on Lyapunov based analytical convergence investigation of distributed flocking control for non-holonomic systems in present of obstacles. [14], [15] have expand some results for Lyapunov based obstacle avoidance strategies; however, those papers do not consider non-holonomic agents with makes our proposal different from them.

For reaching these goal, we might need some assumption on obstacle in sense that it can be distinguished by each agent. Probably, the simplest way to do that is to assume obstacle has all communication equipment like other agents expect it cannot move or move independently of our control scheme (we have no control on it). Although this assumption seems to be unrealistic one, it practical, agents can obtain some information from obstacle using proxy or other environmental sensors. So the results are yet valid for other kind of obstacles.

Another issue, that I think worth to be consider, is considering the problem in case having uncertainty in measuring. That means we need to use estimator of deal noisy measurement. I am afraid that it might be over the scope of this course and also achieving results takes more time than end of the semester. But I think it still worths to be considered .

Also, we can probably do the measure estimator as part of research project for course EE502 in next semester.

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