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To someone very special...

Acknowledgments

Abstract

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Introduction

Chapter 1

State of the art

The literature about the "Consensus" is grown significantly in the latest years because of the increasing presence of autonomous vehicles. This, in accordance with the new improvements in robotics, has brought a growing interest in consensus between multiple agents which have to accomplish a mission in cooperative or adversarial scenarios.

The "Consensus" theory takes its roots in Graph Theory and Automatics and it can be used to coordinate a mission in order to achieve the synchronization between the vehicles even when there might be some unforeseens which force one or more components of the mission to change the planned trajectory or task. In this case, the other components identify this variation and they will act for preserving the synchronization.

The "Consensus" algorithm is a distributed algorithm which sometimes can be simulated in a centralized fashion because of the reduced computational power of the machines involved in the mission, which are equipped with low power hardware to account for the crucial issue of power consumption. In this scenario, a centralized server simulates the algorithm and communicates with all the machines.

The most common "Consensus" application is a spatial and timing consensus.

Each vehicle of the formation has to travel along a specified trajectory and the completion of the mission occurs when all the agents reach the final positions of their spatial paths. The algorithm has to guarantee the difference between the ending time at which all the vehicles finish their tasks is minimized and asymptotically goes to zero when the execution time goes to infinity and no other unforeseen happens. We also consider formations of Unmanned Aerial Vehicles but the key concepts can be freely applied to other categories of robots when they are able to follow a trajectory. This study is focused on this kind of application and further simulation result and experimental achievements are presented in the chapters 5 and 6.

In the following we refer to the main work of Venanzio Cichella in this field [2] in order to provide an homogeneous state of the art about the "Consensus". The paper considers all the details needed to build a "Consensus" system. We can identify the main components of this kind of systems:

- Parametrized trajectory
- Virtual time
- Consensus law
- Network topology

1.1 Parametrized trajectory

The trajectory is a spatial path with associated a timing law and it is used to identify position and orientation of the center of mass of our agent in the space. We can start with the following definition of a generic trajectory $p_{d,i}(t_d)$ for N vehicles:

$$p_{d,i} : [0, t_{d,i}^f] \rightarrow \mathbb{R}^3, \quad i = 1, 2, \ldots, N \tag{1.1}$$

where $t_d \in [0, T_d]$, with $T_d := max\{t^f_{d,1}, \dots, t^f_{d,N}\}$, is the time variable of the trajectory, while $t^f_{d,i} \in \mathbb{R}^+$ are the individual final mission times of the vehicles obtaining during the planning phase. Usually all this final times are equal and therefore $t^f_{d,1} = \cdots = t^f_{d,N} = T_d$, but we introduced the notation for the sake of completeness. Obviously the trajectories need to be collision free and must satisfy spatial and temporal constraints due to the dimension of the vehicle and its maximum velocities and accelerations.

We now parametrize the trajectory using a dimensionless variable $\zeta_i \in [0, 1]$, related to the time t_d. In this way we can specify a function $\theta(\cdot)$, which represents the timing law associated with the spatial path $p_{d,i}(\zeta_i)$. We can specify this timing law using the dynamic relation of the form:

$$\theta(t_d) = \frac{d\zeta_i}{dt_d} \tag{1.2}$$

where $\theta(t_d)$ is a smooth and positive (the parameter increases when the time increases) function.

It is desirable that an analytical expression for the function $\zeta_i(t_d)$ to be available, since it allows a one-to-one correspondence between the time variable t_d and the parameter ζ_i. Using the timing law, defined in (1.2), the map $\zeta_i(t_d)$ is given by the integral:

$$\zeta(t_d) = \int_0^{t_d} \theta_i(\tau) d\tau \tag{1.3}$$

Usually, all this functions are defined as polynomials in order to make quicker and easier the evaluation process, since multiplication and addition are the basic operations in a digital processor, but it is not mandatory to use them and a generic shape for the functions can be designed. We have defined all the elements of a trajectory and we do not enter in details about the trajectory generation phase. Further details about boundary conditions and flyable trajectory which satisfy the dynamic constraints of the vehicles can be found in [2] and are extensively presented in [1], [3], [4].

1.2 Virtual time

1.3 Consensus law

1.4 Network topology

Chapter 2

Consensus

Chapter 3

System architecture

Chapter 4

Consensus node

Chapter 5

Simulation results

Chapter 6

Experimental results

Conclusions

Bibliography

[1] R. Choe, J. Puig-Navarro, V. Cichella, E. Xargay, and N. Hovakimyan. Trajectory generation using spatial Pythagorean Hodograph Bezier curves. *in Proc. AIAA Guidance, Navigation and Control Conf., Kissimmee, FL*, 2015.

[2] V. Cichella, R. Choe, S. B. Mehdi, E. Xargay, N. Hovakimyan, V. Dobrokhodov, I. Kaminer, A. M. Pascoal, and A. P. Aguiar. Safe coordinated manuvering of teams of multirotor unmanned aerial vehicles. *IEE Control systems magazine*, August 2016.

[3] V. T. Taranenko. Experience of Employment of Ritz's, Poincare's, and Lyapunov's Methods for Solving Flight Dynamics Problems. *Moscow: Air Force Engineering Academy Press*, 1968.

[4] O. A. Yakimenko. Direct method for rapid prototyping of near-optimal aircraft trajectories. *J. Guidance, Control Dyn.*, 23(5):865–875, Sept.-Oct. 2000.

Appendix A

First appendix

Appendix B

Second appendix

Appendix C

Third appendix