Goal. Quadcopters are being used across a wide range of applications. These include search, reconnaissance, rescue, law enforcement, surveillance, environment mapping, area/warehouse/agriculture/infrastructure inspection, etc [1]. Given my desire to become an expert in this area, the primary goal of this project is to gain substantive experience in the growing area of intelligent autonomous systems [1]. This will be achieved by developing algorithms to permit a fully instrumented quadcopter – with a camera, inertial measurement unit (IMU), and lidar [2] – to follow (track) a moving ground vehicle within a prescribed distance. Three tracking methods will be carefully examined.

Motivation. The proposed tracking quad-follow-car scenario has a wide range of applications. This includes law enforcement (e.g. following a car containing suspected felons to avoid a high-speed pursuit) [3]. Given this, it can be seen that the there are many applications for the proposed work (e.g. assisting law enforcement and first responders, security, area/warehouse/agriculture/infrastructure inspection) [4].

Work accomplished during FURI 1 (Spring 2018). A quadcopter has already been assembled to track a ground vehicle via colored marker on the vehicle. A Raspberry Pi was used to implement the image processing. Because of Raspberry Pi limitations, tracking can only be accomplished at low speeds. This is unacceptable. To remedy this an Nvidia TX2 with 256 graphical processing unit (GPU) cores was obtained. This can achieve nearly 30 frames per second at high resolution – acceptable for rapid image processing applications such as ours. This work has provided a foundation for the proposed FURI 2 work.

Overview of work to be accomplished during FURI 2 (Fall 2018). Moving forward, it is crucial to implement and compare various forms of tracking. This is important to understand fundamental (reliability, speed, cost) tradeoffs. Our ultimate goal is to be able to tightly coordinate multiple air and ground vehicles in a space. The proposed work will lay a foundation for this more advanced future career-shaping work. During FURI 2, three tracking methods will be examined. One based on a colored marker on the car, a second based on using a neural network (machine learning approach) [5] to directly identify the car (based on a photo or a license plate) and the last method will use a newly purchased precision (sub-milimeter) indoor tracking system that can send car-and-quad position data directly to the quadcopter. The results obtained using each tracking method will be compared. Important (reliability, speed, cost) tradeoffs will be illuminated. It should be noted that the quadcopter control system makes use of the onboard inertial measurement unit (IMU) – accelerometers and gyroscopes – in order to stabilize the vehicle, permit reliable video capture and follow speed, direction and position commands [6] issued by a remotely situated operator (via 2.4 GHz spread-spectrum communications link) or by a smart tracking algorithm [7]. A proportional-plus-integral-plus derivative (PID) tracking law implementation [7] will be part of the proposed spacing algorithm work. This will require mathematical modeling [8], model analysis [9], model-based control design and
simulation using MATLAB/Simulink [9]. Basic quadcopter features to be implemented will include (1) an immediate shutdown feature, (2) a safe landing feature [10] and (3) a return to operator feature [10].

**AUTOMATIC FOLLOWING USING THREE TRACKING METHODS.** While the quadcopter will provide real-time visual feedback to a remotely-situated operator in order to enable manual control and following of a car, one key goal will be to implement automatic vehicle following algorithms [11]. These algorithms can use the onboard camera, lidar and GPS [12]. Tracking algorithms to be developed will be based on marker tracking, car identification using a neural network (machine learning) and using an indoor tracking system. Simple camera-based image processing algorithms will rely on finding a predetermined marker in the image plane [13]. A critical issue here is speed. That is, we want to be able to find the marker quickly in order to permit reasonable tracking of the vehicle [14]. The Nvidia TX2 will permit this. Next, the marker will be removed and a neural network (machine learning) will be used to recognize specifics about the ground vehicle that can be used for vehicle tracking. Vehicle specifics can include but is not limited to a license plate number, color of vehicle, type of vehicle (i.e truck, semi, sedan, ford, chevy, etc.) [15]. Finally, the recently purchased indoor tracking system will permit precision (sub-milimeter) tracking [16], [17] by communicating relevant 6dof data directly to the quadcopter.

**AVAILABLE HARDWARE.** For the proposed work, we will use an available quadcopter and an available ground vehicle (i.e. small RC car). The quadcopter and ground vehicle have already been built [4], the quadrotor has been programed for a follow ahead feature with a raspberry pi. To implement a more reliable system, an Nvidia board will be mounted to the quadcopter for high quality image processing. An Otus indoor tracking system is also available [18]. The quadrotor will need to be programed to accommodate each of the tracking algorithms.

**FINAL DEMONSTRATION AND DOCUMENTATION.** The final presentation will show how the three tracking algorithms perform. All results, models and procedures will be summarized within a comprehensive final report and poster. Results will be submitted for publication in the proceedings of the American Control Conference (ACC), Frontiers in Education (FIE) and ASEE Conferences. Other publication venues will be examined.

**CAREER RELVANCE.** This work will provide a foundation for more advanced work – work that I plan to pursue as a direct PhD. To enable my PhD dreams, I’ll be applying for an NSF Fellowship this coming Fall. My Spring 2018 FURI 1 and Fall 2018 FURI 2 work, as well as my planned Summer 2018, Spring 2019 and Summer 2019 work with Dr. Rodriguez (see below) will provide a very solid foundation for my proposed doctoral work. After receiving my PhD, I hope to conduct and supervise research at a Research 1 university, mentor students, consult with industry and contribute to the intelligent/autonomous system revolution that is upon us.

**FURI ADVISOR.** Dr. Rodriguez has worked in the area of Flexible Autonomous Machines operating in an uncertain Environment (FAME) for over 30 years. He has supervised over 50 graduate theses and over 300 projects. Relevant theses are as follows: [4], [6], [7], [8], [9]. Recently, Dr. Rodriguez led a team of ASU students to become finalists in the ASU ASURE 2017 Innovation Challenge. He is also the PI of a 5 Year, $5M NSF funded Scholarship program. Each scholar is required to work on a career-shaping project. I am a scholar in his program. The proposed FURI will permit me to work with Dr. Rodriguez alongside a team of highly motivated graduate and undergraduate students – all working in the area of intelligent autonomous systems.
References


## Precision Following of a Ground Vehicle Time Line

**FURI Fall 2018**

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