Autonomous Drone Racing

Student: Midn 2/C A. Credle Adviser: Asst. Prof. D. Evangelista

***Abstract*—Add the abstract last after all other sections have been completed. The abstract should be a summary of the entire proposal, including elements from each section -- not just the problem statement. It should be self-contained, which means it should not include undefined acronyms or cross references. Keep it under 250 words. You can check by highlighting it and selecting Review/Word Count.**

I. Background and Motivation

Insert your motivation section here. It should be 1-2 pages in length, and include 1-2 figures and 5 references. In this section it may be appropriate to cite popular press articles (be sure to use IEEE format – see class notes). Your goals are to:

- educate the reader on your broad topic area;
- define any unfamiliar terms, concepts or acronyms;
- describe how your specific topic fits in a larger engineering context;
- discusses economic, societal, or policy impacts; and
- present current or future applications of your topic area.

II. Problem Statement

Given a small quadrotor drone with an inertial measurement unit (IMU) and a single camera, this research intends to begin the process of developing autonomous drone flight through a drone racing course. Given both a preloaded three dimensional path, we will find and test the feasibility of a guidance system that collaborates computer vision with the preloaded path. This system will be tested by placing a small quadrotor in multiple scenarios in relation to a race gate(s), with varying angles of approach and gate sizes, and directing the guidance system to fly the drone through the race gate(s). Success of this system is having the drone autonomously fly through multiple race gates(?) without contact in every scenario given at the drones maximum horizontal speed. The final output of this project will a guidance system that could be implemented on any racing drone with a camera and IMU and fly through multiple race gates.

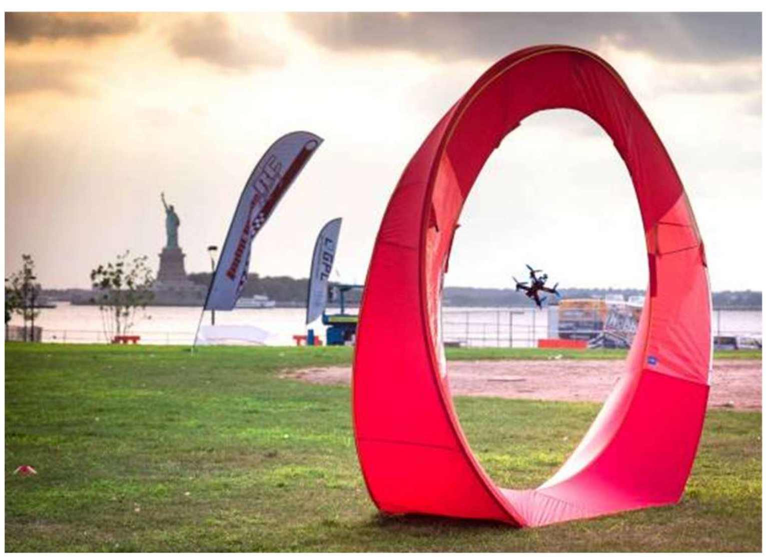

Figure 1: A quadcopter drone flying through a racing gate.

III. Literature Review

This section should be approximately 2 pages in length and discusses *at least* 6 peer reviewed technical papers. Dedicate about one paragraph per reference describing its contribution, strengths and limitations. Order the paragraphs using a "funnel" organization, starting with broad/loose relation to moving to the most closely related works.

Include a penultimate paragraph which groups, critiques or compares the 6 related works. Optionally, you may include graphic, such as a table or Venn diagram that shows how the papers fit together.

The final paragraph should describe how your proposed research fits in with, or uses results/techniques from existing work and makes the case it is novel.

Check that your citations insert correctly, that they are discussed by numbered reference (not using author's name or affiliation), that you use IEEE format and that each paper appears only *once* in the reference section at the end of the proposal (even if it is cited multiple times in the paper).

This paper is the first developments of a drone autonomous flight program, so the background research encompasses papers that focus on multiple aspects of autonomous flight. The main categories that these papers fall into include navigation, flight controls, and visual recognition. This research focuses on the visual recognition of the gate, but these other two categories are necessary for the background research because they affect the performance of visual recognition and are necessary for basic demonstration.

In order to understand the movement patterns of the drone, [1] provides a set of equations that could be used to accurately model the induced drag and thrust forces. These equations were derived from proofs using properties of physics, and then the coefficients were identified through flight experimentation. This allows provides suitable estimations for the forces acting on the drone, which allows for control of the drone through the gate. This is connected to [2], which created a state equation set that could accurately model the movement of a small drone with aggressive flight. By determining these equations through modeling and live testing, these state equations can be coupled with the flight force equations from [1] to form an accurate estimate of the drones location. Coupling these with a flight controller will allow the drone to have a basic understanding of its location as compared to the general space. This research is centered around coupling visual servoing and preprogrammed flight paths, and in order to understand the drones relation to the preprogrammed flight path, [1] and [2] provide an accurate location.

While [1] and [2] provide what is believed to be an accurate location of the drone in-flight, it's location in relation to the preprogrammed flight path isnt always certain. [3] provides the groundwork for a concept known as Nano Mapping, which refers to modeling a 3D data structure depicting obstacles around the drone. This technique is different from a traditional mapping approach because tradtional mapping is based of a common world frame. [3] is based solely on the frame of the drone, allowing for a calculatable uncertainty to enter trajectory planning. This concept is also crucial to the development of this research because the coupled flight path planning approach requires both the common world frame and the drone world frame.

Different methods for seeing the world around the drone exist, including range finding technology (used for altitude measurements), single camera, and multi camera approaches. [2] is based on a single camera approach, while [4] found that a three camera setup was optimal for uncertain terrains. [4] is based on autonimous navigation of drones in a wooded area, where to location of the trees is unknown before flight, and path recognition is taught to the drone using AI. While the racecourse for this research is assumed to be known, a single camera apporach will be utilized for hardware simplicity; the AI approach of path recognition, however, may be utilized in this research's gate recognition technology. If a neural network could be constructed to follow a path through a forest, a similar neural network could be formed to fly through an ariel path.

One of the main challenge that arises with flying through the gate is recognizing multiple gates. In small drone racing courses, it is likely that the drone will be able to see multiple gates within its field of view. [5] worked through this problem and found resonable neural network perameters to mitigate this issue. By assuming the next gate in the racecourse would be the largest gate in the drone camera view (using a single camera approach), [5] removed the nueral network layer of all image analysis and left only the recognition of the largest circle gate. By removing this process in the image analysis, [5] found a significant increase in processing power while only reducting the accuracy of gate recognition by less than 10% (464ms to 34ms reaction time, 82.4% to 75.5%).

The other main challenge that arises after rocognizing the proper gate to fly through is implementing a visual servoing program to direct the drone through the gate. [6] created a process of gate recognition that located the center of the gate in relation to the location of the center of the cameras view and redirecting the drone towards the center of the gate. This background research is the closest process to the research in this paper, as it specificies a visual recognition procesc that is simplified into the computational level of an inflight processor.

While many of these papers are useful in the development of an autonimous drone, it should be noted that there lacks a consistancy among drone researchers in the underlying assumptions. As described earlier, some researchers utilize a single camera operating system, while others use multi-camera systems, and even some include range finding technology. Many of the subjects of these papers devled into different subsections of drone autonomy, so it is reasonable that their methods varied, but many of these research projects should have been underwent with a more uniform drone system in place for practicality. For research such as [1], [2], and [3], their research was more for drone flight in general, so this critique doesn't apply as much as it does for projects such as [4], [5], and [6], which had varying sensor and visual capabilities. As the latter 3 projects had more to do with direct visual recognition, it would have been more advantageous for the autonimous drone community had the projects been embarked on in a similar manner.

These projects center around the research in this proposal in two ways: by giving basic flight control and navigational equations to use in baseline location estimations and flight controllers, and by providing simplistic approaches to visual recognition to model my approach. While my approach uses both a whole world frame and a drone view frame to form a novel approach to gate recognition, many of the approaches depicted in [4], [5], and [6] can be used to model a realistic approach to melding the two frames. This project will take these simplistic approaches and form a simple and novel approach to visual gate recognition.

IV. Demonstration plan

This section is the most substantial and part of your proposal. Typically it is 3 pages or longer (including figure) and includes many details.

Begin with an overview paragraph briefly stating what types of demonstrations will be used: proofs, simulations, or experiments. You must justify this choice in terms of Generality, Replicability, Realism and Control. See class notes for more details.

Only include the relevant subsections below from A,B and/or C. All proposals include subsections D-H.

A. *Mathematical analysis*

If your project involves modeling or proving theorems you should outline your argument, review similar proofs or describe analysis techniques. If you plan to use a new control design technique, explain the method with equations and examples.

When discussing math, be sure to define the variables. Equations should be part of a sentence and punctuated as such. They should be numbered for cross referencing as in,

$$y=mx+b. \qquad (1)$$

B. *Simulation or computational studies*

If your project involves simulations or computational studies describe there here. List the inputs, outputs and parameters of the model or functions. Decompose complex simulations into sub-systems or sub-routines. Include either a simulation diagram, flowchart or pseudo code. For simulation diagrams each signal and block should be labeled. For each block dedicate about a paragraph for explaination. Use the `pseudo-code style` inside a text box for algorithms.

Describe the software package, or programming language used as well as any non-standard computing hardware. If you will use any databases or publically available data-sets describe them here.

If you are planning multiple simulations, for example using different data-sets, parameter values, initial conditions, etc. list them here. Tabular format or an itemized list might be appropriate.

C. *Experimental work*

If your project involves either proof-of-concept experiments or statistically repeatable trials describe your plan here. Include at a minimum a functional block diagram with each signal and block labeled. Conceptual, mechanical or circuit drawings should be included. Include photos of key components and justify component selection with basic engineering calculations. Are the sensors you have selected accurate enough to demonstrate the property in question? Address electrical power needs. What voltage do the various components require?

If your plan to do statistically repeatable testing, include the number of trials, subjects, and conditions here as well. You should explain what the controlled variables are and how you plan to statistically analyze the results. If your work involved human subjects you should include a justification for this as well as any documents required by the HRPP office.

D. *Property Measurement*

Regardless of the approach used, a research project demonstrates the properties of a process -- how will these properties be measured and quantified? This includes physical measurements (sensors, calibration, "ground truth") as well as subjective properties like "easy to use" or "robust". If you plan to turn a quantitative measurement into a yes/no answer, provide a threshold value or rating scale along with justification. This justification should be based on some external standard or related work whenever possible.

E. *Technical risks and mitigation*

Is there any part of your project that may just not work at all? For experimental studies, is there any possibility of losing or destroying some critical piece of equipment? Are there safety concerns?

F. *Time risks and mitigation*

Every project has time risks. Cross reference and discuss your Gantt chart here (it will be included in the Appendix). The best practices for mitigating time risk is to start with as many off the shelf components as possible; use existing code and data-sets; schedule as many tasks in parallel; order parts and shop work as soon as possible. Is your project weather dependent or does it require access to any special facilities?

G. *Justification of special high risk activities*

These are: (1) buying parts > $3500; (2) testing on human or animal subjects; (3) learning a new programming language; (4) working in a subject area new to the student *and adviser*; (5) designing and building a system from scratch; or (6) interfacing with new or undocumented hardware or software.

H. *Budget*

Insert your budget as in Table 1. Be sure to discuss any new equipment expenditures.

TABLE 1
BUDGET

LABOR	Category	Hours	hourly rate	Cost
	Midshipman	336	$25	$8,400
	Faculty	64	$60	$3,840
	Staff	45	$40	$1,800
Sub-total				**$14,040**

OVERHEAD	Category	Base Amount	Rate	Cost
	Fringe Benefits	$14,040	35%	$4,914
	Facilities	$14,040	50%	$7,020
	General Service	$14,040	15%	$2,106
Sub-total				**$14,040**

MATERIALS	Category	Items		Cost Estimate
	In-stock Items	Item 1		$150
		Item 2		$500
	To be purchased	Item 1		$200.00
		Item 2		$100.00
Sub-total				**$950.00**

TOTAL COST	**$29,030**
OUT-OF-POCKET COST	**$950**

V. CONCLUSION

A brief conclusion will summarize the process, properties and proposed demonstration, explaining why the project is novel and important. You should also re-state the biggest risk and the steps you will be taking to mitigate it.

Do not introduce any new ideas in this section. Do not include exaggerated claims of the importance of your work.

REFERENCES

[1] S. James, M. Kartik and K. Vijay, "Improving Quadrotor Trajectory Tracking by Compensating for Aerodynamic Effects," in *International Conference on Unmanned Aircraft Systems (ICUAS)*, Miami, FL, USA, 2017.

[2] L. Giuseppe, B. Chris, M. gary and K. Vijay, "Estimation, Control, and Planning for Aggressive Flight With a Small Quadrotor With a Single Camera and IMU," *IEEE Robotics and Automation Letters,* vol. 2, no. 2, pp. 404-411, 2017.

[3] P. R. Florence, C. John, W. Jake and T. Russ, "NanoMap: Fast, Uncertainty-Aware Proximity Queries with Lazy Search over Local 3D Data," CSAIL, Massachusetts Institute of Technology, Cambridge, MA, USA, 2018.

[4] A. A. Zhilenkov and I. R. Epifantsev, "The Use of Convolution Artificial Neural Networks for Drones Autonomous Trajectory Planning," Faculty of Control Systems and Robotics, Department of Control Systems and Informatics, ITMO University, Saint Petersburg, Russia, 2018.

[5] S. Jung, S. Hwang, H. Shin and D. H. Shim, "Perception, Guidance, and Navigation for Indoor Autonomous Drone Racing Using Deep Learning," *IEEE Robotics and Automation Letters,* vol. 3, no. 3, pp. 2539-2544, 2018.

[6] J. Sunggoo, C. Sungwook, L. Dasol, L. Hanseob and S. D. H., "A direct visual servoing-based framework for the 2016 IROS Autonomous Drone Racing Challenge," Unmanned Systems Research Group, Department of Aerospace Engineering, Korea Advanced Institute of Science and Technology, Daejeon, Republic of Korea, 2017.

Appendix: Gantt Chart

Insert the Gantt chart here. Be sure the font is legible. Crop it tight, use landscape orientation and make it as large as possible.

	Task Name	Duration	Start	Finish
1	**ES502 Research**	**87 days**	**Mon 1/6/14**	**Tue 5/6/14**
2	Preliminary Design	48 days	Mon 1/6/14	Wed 3/12/14
3	Preliminary Presentation/ White Paper	1 day	Thu 3/13/14	Thu 3/13/14
4	Detailed Design	37 days	Fri 3/14/14	Mon 5/5/14
5	Final Presentation/ White Paper	1 day	Tue 5/6/14	Tue 5/6/14
6	**Preparation**	**11 days**	**Mon 8/18/14**	**Mon 9/1/14**
7	Familiarization with UGV/UAV platform	11 days	Mon 8/18/14	Mon 9/1/14
8	Familiarization with coding language	11 days	Mon 8/18/14	Mon 9/1/14
9	Familiarization with sensors	11 days	Mon 8/18/14	Mon 9/1/14
10	Design and construct landing platform	11 days	Mon 8/18/14	Mon 9/1/14
11	**Sensor Implementation**	**45 days**	**Mon 9/1/14**	**Fri 10/31/14**
12	Test and calibrate	11 days	Mon 9/1/14	Mon 9/15/14
13	Attach to platforms and familiarize	11 days	Tue 9/16/14	Tue 9/30/14
14	Test connection (receive and send data/ respond correctly to commands)	23 days	Wed 10/1/14	Fri 10/31/14
15	**Connectivity**	**45 days**	**Mon 9/1/14**	**Fri 10/31/14**
16	Establish Wi-Fi network	11 days	Mon 9/1/14	Mon 9/15/14
17	**UGV**	**35 days**	**Mon 9/15/14**	**Fri 10/31/14**
18	Establish functioning wired connection between user and UGV	23 days	Mon 9/15/14	Wed 10/15/14
19	Attach and configure wireless adapter	6 days	Thu 10/16/14	Thu 10/23/14
20	Test functionality of wireless connection	6 days	Fri 10/24/14	Fri 10/31/14
21	**UAV**	**34 days**	**Mon 9/15/14**	**Thu 10/30/14**
22	Attach and configure wireless adapters	28 days	Mon 9/15/14	Wed 10/22/14
23	Test functionality of wireless connections	6 days	Thu 10/23/14	Thu 10/30/14
24	**Coding**	**130 days**	**Mon 11/3/14**	**Fri 5/1/15**
25	**Implement control laws for basic vehicle movement**	**20 days**	**Mon 11/3/14**	**Fri 11/28/14**
26	UGV	20 days	Mon 11/3/14	Fri 11/28/14
27	UAV (stable maneuvering and hovering)	20 days	Mon 11/3/14	Fri 11/28/14
28	**Implement control laws for tracking/ following relationship**	**90 days**	**Fri 11/28/14**	**Thu 4/2/15**
29	for user-controlled UGV	50 days	Fri 11/28/14	Thu 2/5/15
30	for user-controlled UAV	40 days	Fri 2/6/15	Thu 4/2/15
31	**Implement control laws for VTOL**	**111 days**	**Fri 11/28/14**	**Fri 5/1/15**
32	**Stable take-off upon user command**	**88 days**	**Fri 11/28/14**	**Tue 3/31/15**
33	while UGV is stationary	31 days	Fri 11/28/14	Fri 1/9/15
34	while UGV is moving	35 days	Wed 2/11/15	Tue 3/31/15
35	**Stable landing upon user command**	**80 days**	**Mon 1/12/15**	**Fri 5/1/15**
36	while UGV is stationary	22 days	Mon 1/12/15	Tue 2/10/15
37	while UGV is moving	22 days	Thu 4/2/15	Fri 5/1/15
38	Final Capstone Presentation	1 day	Fri 5/1/15	Fri 5/1/15