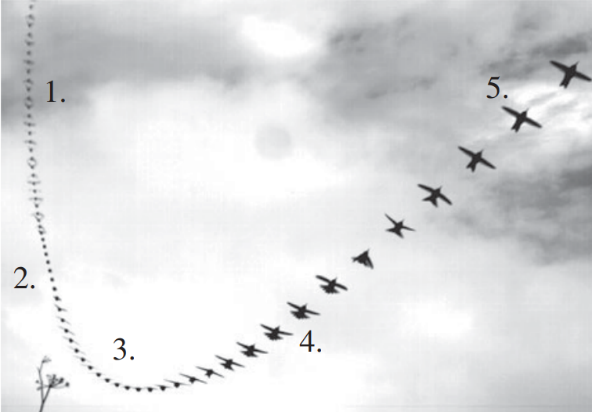
**EW495 Final Report**

Autonomous trajectory planning to execute extreme maneuvers based on hummingbird display dives

****

**Author:** MIDN 1/C Marcello  
**Date:** Dec. 5th, 2019

**Adviser:** Prof. D. Evangelista

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ \_\_\_\_\_\_\_\_\_\_\_  
(signature) (date)

**Department Chair:** Prof. B. E. Bishop

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ \_\_\_\_\_\_\_\_\_\_\_  
(signature) (date)

Project Title

Student: Midn 2/C D. Young Adviser: Asst. Prof. L. Smith

*Abstract*—Add the abstract last after all other sections have been completed. The abstract should be a summary of the entire report, 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.

# 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.

# Problem Statement

Insert your problem statement here. It should be less than 1 page in length and include a figure (see Figure 1). Consider using a common format such as “given-find”, hypothesis, or “research questions”. Be sure to clearly define the process you intend to study, the properties you will demonstrate and explicitly state any assumptions needed to make your problem tractable.

Figure 1: A star.

# Literature Review

This section should be approximately 2 pages in length and discusses *at least* 6 peer reviewed technical papers. Popular press articles should not be used in this section. Dedicate about one paragraph per reference (or group of similar references) 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 report (even if it is cited multiple times in the paper).

# Demonstrations

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

Begin with an overview paragraph briefly stating what types of demonstrations were used: proofs, simulations, or experiments.

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

## 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,

(1)

## 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.

## 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.

## 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.

## Schedule

Discuss if your project is on schedule. What put you ahead or behind? Can you recover? What the plan for next semester (if applicable).

## 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 |
| **Labor Sub-total** |  |  |  | **$14,040** |
| **OVERHEAD** | **Category** | **Base Amount** | **Rate** | **Cost** |
|  | Fringe Benefits | $14,040 | 35% | $4,914 |
|  | Facilities | $14,040 | 50% | $7,020 |
|  | General Services | $14,040 | 15% | $2,106 |
| **Overhead Sub-total** |  |  |  | **$14,040** |
| **MATERIALS** | **Category** |  |  | **Cost** |
|  | In-stock Items |  |  | $817 |
|  | New Items |  |  | $820 |
| **Materials Sub-total** |  |  |  | **$1,637** |
| **TOTAL COST** |  |  |  | **$29,717** |
| **OUT-OF-POCKET COST** |  |  |  | **$820** |

\*Disclaimer: Labor and overhead costs are estimated only for EW502 training purposes and do not actually reflect real costs that would be supported by project sponsors. Additionally, there are no new costs predicted for the spring semester.

# Conclusion

A brief conclusion will summarize the process, properties and proposed demonstration, explaining why the project is novel and important. Do not introduce any new ideas in this section.

Include a substantial discussion of future work (i.e. next semester for Fall projects).

Do not include exaggerated claims of the importance of your work.

References

[1]R. NORBERG, "AUTOROTATION, SELF-STABILITY, AND STRUCTURE OF SINGLE-WINGED FRUITS AND SEEDS (SAMARAS) WITH COMPARATIVE REMARKS ON ANIMAL FLIGHT", *Research Gate*, 1973. [Online]. Available: https://www.researchgate.net/publication/229965983\_Autorotation\_self\_stability\_and\_structure\_of\_single\_winged\_fruits\_and\_seeds\_Samaras\_with\_comparative\_remarks\_on\_animal\_flight. [Accessed: 04- May- 2019]

[2]"Maple Seeds Inspire Robotic Flight", *Aero.umd.edu*, 2019. [Online]. Available: https://aero.umd.edu/news/story/maple-seeds-inspire-robotic-flight. [Accessed: 19- Mar- 2019]

[3] Feltman, Rachel. *. Creepy Robots Help Researchers Understand the Mysterious Sidewinder Snake*. Washington: WP Company LLC d/b/a The Washington Post, 2014, https://search.proquest.com/docview/1609471314?accountid=14748 (accessed March 19, 2019).

[4] J. Larimer and R. Dudley, "Accelerational Implications of Hummingbird Display Dives", *The Auk*, vol. 112, no. 4, pp. 1064-1066, 1995 [Online]. Available: https://www.jstor.org/stable/4089044?Search=yes&resultItemClick=true&searchText=%28%28hummingbird%29&searchText=AND&searchText=%28dive%29%29&searchUri=%2Faction%2FdoBasicSearch%3FQuery%3D%2528%2528hummingbird%2529%2BAND%2B%2528dive%2529%2529&ab\_segments=0%2Fdefault-1%2Frelevance\_config\_with\_defaults&refreqid=search%3A045626d07ba91ba3c65c3041c3083b18&seq=2#metadata\_info\_tab\_contents. [Accessed: 08- Feb- 2019]

[5]C. Clark, "Courtship dives of Anna's hummingbird offer insights into flight performance limits", Proceedings of the Royal Society B: Biological Sciences, vol. 276, no. 1670, pp. 3047-3052, 2009 [Online]. Available: https://royalsocietypublishing.org/doi/pdf/10.1098/rspb.2009.0508. [Accessed: 19- Feb- 2019]

[6] B. G. Hogan and M. C. Stoddard, “Synchronization of speed, sound and iridescent color in a hummingbird aerial courtship dive,” *Nat. Commun.*, vol. 9, no. 1, p. 5260, Dec. 2018.

[7] C. J. Clark and T. J. Feo, “The {A}nna’s {H}ummingbird chirps with its tail: a new mechanism of sonation in birds,” *Proc. R. Soc. B*, vol. 275, no. 1637, pp. 955–962, Jul. 2008.

[8]D. Mellinger and V. Kumar, "Minimum snap trajectory generation and control for quadrotors," 2011 IEEE International Conference on Robotics and Automation, Shanghai, 2011, pp. 2520-2525 [Online]. Available: http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=5980809&isnumber=5979525. [Accessed: 19- Feb- 2019]

[9] M. Greiff, “Modelling and Control of the Crazyflie Quadrotor for Aggressive and Autonomous Flight by Optical Flow Driven State Estimation,” Lund University Department of Automatic Control, 2017.

[10]B. Cheng, B. Tobalske, D. Powers, T. Hedrick, S. Wethington, G. Chiu and X. Deng, "Flight mechanics and control of escape manoeuvres in hummingbirds. I. Flight kinematics", *The Journal of Experimental Biology*, vol. 219, no. 22, pp. 3518-3531, 2016 [Online]. Available: http://jeb.biologists.org/content/219/22/3518. [Accessed: 08- Feb- 2019]

[11] D. H. Theriault *et al.*, “A protocol and calibration method for accurate multi-camera field videography,” *J. Exp. Biol.*, vol. 217, no. February, p. jeb--100529, Feb. 2014.

[12] K. M. Sholtis, R. M. Shelton, and T. L. Hedrick, “Field Flight Dynamics of Hummingbirds during Territory Encroachment and Defense,” *PLoS One*, vol. 10, no. 6, p. e0125659, Jun. 2015.

[13] B. E. Jackson, D. J. Evangelista, D. D. Ray, and T. L. Hedrick, “3D for the people: multi-camera motion capture in the field with consumer-grade cameras and open source software,” *Biol. Open*, vol. 5, no. 9, p. bio.018713, 2016.

[14]T. Tomić, M. Maier, and S. Haddadin, “Learning quadrotor maneuvers from optimal control and generalizing in real-time,” in *2014 IEEE International Conference on Robotics and Automation (ICRA)*, 2014, no. Section III, pp. 1747–1754.

[15] F. Sabatino, “Quadrotor control: modeling, nonlinear control design, and simulation,” KTH Royal Institute of Technology in Stockholm, 2015.

[16] S. Liu, M. Watterson, K. Mohta, K. Sun, S. Bhattacharya, C. J. Taylor, and V. Kumar, “Planning Dynamically Feasible Trajectories for Quadrotors Using Safe Flight Corridors in 3-D Complex Environments,” *IEEE Robot. Autom. Lett.*, vol. 2, no. 3, pp. 1688–1695, 2017.

[17] David(dch33), “Quadrotor Dynamic Modeling and Simulation”, Web. 13 Nisan 2015. https://github.com/dch33/Quad-Sim. (Date of access: 03.05.2019).

[18] J. Gainer, L. Devries, M. Kutzer, “Persistent Target Detection and Tracking by an Autonomous Swarm”, ASME 2018 International Design Engineering Technical Conferences and Computers and Information in Engineering Conference 2018.

[19] B. Canlas, L. Devries, “Shape Formation Control for an Autonomous Swarm”, United States Naval Academy 2015.

Appendix I: TIMELINE

**EW402 - 4 Credits - Spring AY2020**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Week (M)** | | **Note** | **Planned Activities** | **Actual Hrs** |
| 1 | Jan  6 | Begins Tues (M sched) | **Programming**   * Continue work in ROS and Python. * Clone git repository for Crazyflie control with ROS onto linux machine catkin workspace.   **Simulation**   * Refine simulation by adjusting PD control gains. * Give quadrotor initial velocity tangent to desired path to see if this minimizes error. * Re-test trajectories for error relationship with speed. | 5 |
| 2 | J 13 |  | **Hardware/Autonomous Flight**   * Get Crazyflie to hover autonomously using ROS. * Execute a hover-in-place * Repeat hover exercise using OptiTrack for position information. | 10 |
| 3 | J20 | M = MLK Leave  Wed. on MO | **Simulation**   * Test geometrically dilated trajectory that fits in lab space and calculate error. | 2 |
| 4 | J27 |  | **Control Design**   * Model new linearization region to control different parts of the dive (~45-60 degrees of pitch).   **Autonomous Flight**   * Execute waypoint flying on Crazyflie. * Log flight data with OptiTrack. | 7 |
| 5 | Feb 3 |  | **Simulation**   * Implement new controller for specific stages of flight. * Calculate errors. Is it better than before? | 7 |
| 6 | F 10 |  | **Autonomous Flight**   * Test scaled hummingbird trajectories in lab at extremely slow speeds (~1/25 speed or slower) with original position controller. * Results plotted in MATLAB and analyzed. * Adjust gains to obtain less error. | 7 |
| 7 | F 17 | M = Pres Day 6 wk grds W | Determine max speed in simulation for RMS (root mean square) error of less than 10cm using most successful control method. Achieved through running iterations of the simulation with increasing speed until error becomes too great. | 5 |
| 8 | F 24 |  | Test Hummingbird trajectories in lab at speeds close to max simulated speed. Obtain error from data collection. | 5 |
| 9 | Mar 2 | M = Columbus | Adapt controller gains in lab experiment to maximize speed through trial and error. | 5 |
| SB | M 9 |  |  |  |
| 10 | M 16 |  | **Buffer** (complete any outstanding tasks, or compile all experimental results) | 5 |
| 11 | M 23 |  | **Buffer** | 5 |
| 12 | M 30 | Ac Reserve | My 12 week deliverables are:   * Final controller implementation. Fully functional simulation. Max quadrotor speed determined with suffering less than 10cm root mean square error in the trajectory. |  |
| 13 | Apr 6 | 12 wk Grades T | * Demonstration of hardware capabilities. * Share draft poster with adviser for comments.   Use template. | 7 |
| 14 | A 13 |  | * Work on report. Compile all findings. * Submit poster to MSC for printing. | 7 |
| 15 | A 20 |  | * Share draft report with adviser for comments. Use template. * Capstone day | 5 |
| 16 | A 27 | T= last day of class | * Schedule technology transfer with adviser * All work saved in google drive, and code uploaded to Git. | 2 |