AE 5335 – Assignment 1

Collaboration Policy

This is an "open-book and open-notes" assignment, which means that consulting lecture notes/slides provided by the instructor and/or similar educational material from sources on the Internet is allowed. Using MATLAB® or similar software is allowed unless stated otherwise for specific problems. Discussions about this assignment with other students in the class are allowed and encouraged. However, the submitted assignment must reflect your own independent work. Plagiarism from any source is disallowed.

Statement of Academic Honesty: When submitting this assignment, you will be asked to state:

> *My signature below affirms that this submission is entirely my own work, and reflects my own understanding of the course content. This submission does not contain material copied or plagiarised from any other source including works of other students. I have read and I understand WPI's Academic Honesty Policy, and my conduct in preparing this submission has been in accordance with this Policy.*

Instructions for Assignment Submission

- The submission format is a *single* PDF file, to be uploaded via *Canvas*. Multiple files will not be graded.
- Read WPI's Academic Honesty Policy, and the Student Guide to Academic Integrity.
- All deadlines provided are in Eastern Daylight Time. Late submissions will receive a grade penalty as follows.
  - Late by up to 48 hours after deadline: 10% penalty.
  - Late by 48 - 96 hours after deadline: 20% penalty.
  - Late by more than 96 hours after deadline: 30% penalty.
- The solution to each problem should be presented in the following format:
  - **Method:** e.g., "I did [insert basic outline of method] and obtained the following results." OR "I used the [insert name of command/tool/library] from [MATLAB or similar software]. This command/tool/library [insert brief explanation of what the tool does and/or how it works]."
  - **Results:** e.g. "The following plots/numbers/expressions indicate [what they indicate; insert plots / numbers, expressions etc]."
  - **Discussion:** e.g. "The [results above; details] match expected [behavior/values] because [reasons]." OR "The [results above; details] match expected [behavior/values], but may include minor numerical errors because [reasons]." OR "The [results above; details] are not sensible because [explain why you think the results are not correct]. My method appears to be correct, but I was not able to resolve [issue] despite trying [describe your attempts, including discussions, if any, with the instructor and/or TA]."
- Submissions in the form of software code (e.g., MATLAB® code) without an explanation of the method and discussion of results are not acceptable, and such submissions will be returned without grading. If and when code is included in the submission, it must be included as an appendix, not in the main submission.
- Illegible and/or untidy submissions will not be accepted or graded, and the students will forfeit points unless the work is entirely resubmitted. For these resubmissions, lateness penalties as above will apply.
- To scan handwritten work into a PDF file, use either a desktop scanner or a smartphone-based software application such as CamScanner, Microsoft Lens, or Adobe Scan. Watermarks, if any, left by free versions of these software applications are acceptable.
- Consult this page for examples of acceptable and unacceptable assignment submissions.

Data, where provided, are in SI units, i.e., m, kg, s, rad for length, mass, time, and angles. The acceleration due to gravity is 9.81 m/s^2. Assume any Earth-fixed axes system as inertial.

Problem 1. (0 points)

Read the following survey article, provided on Canvas, to supplement the classroom discussion on autonomous aerial vehicles:

> M. Hassanalian and A. Abdelkefi. "Classifications, applications, and design challenges of drones: A review." *Progress in Aerospace Sciences,* 91, 99-131, 2017. https://doi.org/10.1016/j.paerosci.2017.04.003

Problem 2. (0 points)

Read the following tutorial article, provided on Canvas, to supplement the classroom discussion on navigation:

> M. Bryson and S. Sukkarieh. "UAV Localization Using Inertial Sensors and Satellite Positioning Systems." In: Valavanis, K., Vachtsevanos, G. (eds) *Handbook of Unmanned Aerial Vehicles,* Springer, Dordrecht, 2015. https://doi.org/10.1007/978-90-481-9707-1_3

Problem 3. (25 points)

Consider the attitude kinematics equations using Euler angles. Observations are available from the following sensors (all noisy): body-fixed rate gyros $\boldsymbol{r}^{\mathrm{b}}$, body-fixed accelerometers $\boldsymbol{a}^{\mathrm{b}}$, a digital compass m^{b}, and GPS-based aircraft velocity in Earth-fixed coordinates $\boldsymbol{V}^{\mathrm{t}}$. Assume that the aircraft velocity is constant.

Time-stamped synthetic data from these sensors over an interval are provided in the attached data (`.mat`) file. Each sensor is assumed to have normally distributed measurement noise with zero mean and variances as provided in the data file.

Implement an EKF to estimate the Euler angles using these data.

The data file provides the true Euler angles for validating your implementation. Plot the estimation error, i.e., the difference between the true and estimated values to demonstrate that your estimator works correctly.

Problem 4. (25 points)

Consider the attitude kinematics equations using Euler angles. Observations are available from the following sensors (all noisy): body-fixed rate gyros $\boldsymbol{r}^{\mathrm{b}}$, body-fixed accelerometers $\boldsymbol{a}^{\mathrm{b}}$, a digital compass m^{b}, and GPS-based aircraft velocity in Earth-fixed coordinates $\boldsymbol{V}^{\mathrm{t}}$. Assume that the aircraft velocity is constant.

Time-stamped synthetic data from these sensors over an interval are provided in the attached data (`.mat`) file. Each sensor is assumed to have normally distributed measurement noise with variances as provided in the data file. However, each sensor has an unknown bias (i.e., nonzero mean) that is to be estimated.

Implement an EKF to estimate the Euler angles and sensor biases using these data.

The data file provides the true Euler angles for validating your implementation. Plot the estimation error, i.e., the difference between the true and estimated values to demonstrate that your estimator works correctly.

Problem 5. (30 points)

Considering the sensor data and characteristics described in Problem 4, develop EKF equations for quaternion kinematics. Implement the EKF.

The data file provides the true quaternions for validating your implementation. Plot the estimation error, i.e., the difference between the true and estimated values to demonstrate that your estimator works correctly.

Also plot the magnitude of the quaternion mean estimate over time to demonstrate whether or not the unit magnitude property is preserved.

Problem 6. (10 points)

Prepare a short ($\sim$ 500 words) summary of the following article provided on *Canvas*:

> G. Chowdhary, E. N. Johnson, D. Magree, A. Wu, and A. Shein. "GPS-denied indoor and outdoor monocular vision aided navigation and control of unmanned aircraft." *Journal of Field Robotics,* 30(3), 415-438, 2013. https://doi.org/10.1002/rob.21454

Explain what you consider as the main ideas, main findings, and/or weaknesses of the work reported in this article.

Problem 7. (10 points)

Prepare a short ($\sim$ 500 words) summary of the following article provided on *Canvas*:

> M. B. Rhudy, Y. Gu, H. Chao, and J. N. Gross. "Unmanned aerial vehicle navigation using wide-field optical flow and inertial sensors." *Journal of Robotics.* vol. 2015, Article ID 251379. https://doi.org/10.1155/2015/251379

Explain what you consider as the main ideas, main findings, and/or weaknesses of the work reported in this article.