Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

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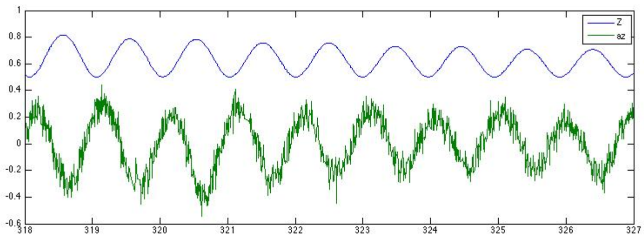
Semester Thesis

Sensor Fusion / State Estimation for a Kite Power Plant



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Sensor Fusion / State Estimation for a Kite Power Plant

Description

Working within the context of the SwissKitePower project,

- Develop and implement a data fusion algorithm that provides a real-time estimation of the kite's position, velocity and orientation using the output from multiple sensors.
- Perform laboratory and field tests to validate and quantify the performance boundaries of the estimator.
- Document the results in a report and presentation.

Tasks

Sensor Selection and preliminary testing:

Researchers at FHNW and ETH have already selected and procured a number of sensors and performed preliminary tests. These sensors include:

- Xsens – Commercial GPS + IMU with extended Kalman filter implemented in on-board DSP. http://www.xsens.com/en/general/mti-g

- ArduPilot – Open source GPS + IMU system with DCM (direction cosine matrix) calculation implemented in on-board microprocessor. http://diydrones.com/profiles/blogs/ardupilot-mega-home-page

- X-IMU – Early commercial IMU with integrated storage and Bluetooth, some sensor fusion implemented on-board. http://www.x-io.co.uk/node/9

In addition, the following sensors have been ordered and will be implemented and tested on the FHNW groundstation during the next set of bachelor thesis projects:

- Line angle sensors from TWK - Both the vertical and horizontal angles and angular rates of change of the kite line

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will be measured using the following sensors. When combined with the length of the line, an estimation of kite position and velocity are possible.
http://www.twk.de/data/pdf/11278fe0.pdf

- Differential GPS system – A DGPS from Novatel has been ordered which consists of two receivers, one which will go on the kite and another on the ground which measures and transmits the correction information.
http://www.novatel.com/assets/Documents/Papers/OEMStar.pdf

Working with the FHNW students, these systems should be tested and the results analyzed to determine the best suitable combination of sensors for the system. Additional sensors, such as the PixIMU from ETH and the new version of the ArduIMU can also be tested and potentially used in the system. First testing can be made using a centrifuge, which is available at FHNW to understand how the various GPSs and IMU's perform under high g-loads and dynamic conditions. Preliminary tests of this nature have been performed and their results documented in a report which is available.

State Estimator Development:

Based on the results of the first task, a first version of the estimation software should be developed and implemented on an appropriate platform. Most likely this can be done on a PC using Labview or Matlab to acquire and process the incoming data streams and to perform the calculations required. A definition should be made for what sensor values will be passed from the FHNW groundstation to the PC which will perform the calculations as well as what form of output will be given. It is possible that not all sensors are available and the algorithm has to be able to deal with different sensor setups. This should be defined during an initialization phase. Different state estimation algorithms should be implemented and tested. Care should be taken how to evaluate the performance of the different algorithms. As a start the conclusion of the Master Thesis of Héjj Andreás "Kalman-filter based position and attitude estimation algorithms for an Inertial Measurement Unit" can be used. From there on it has to be investigated how we can use the model information of the kite system to improve the state estimation. It can either be used for the state propagation of the INS algorithm directly or apply another Kalman filter in an outer loop to estimate the trajectory.

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Testing and Validation:

Working with FHNW students and staff, the estimator should be tested in the loop and its output used in some preliminary stabilizing and tracking controllers. The implementation of the controllers themselves will be the responsibility of the project supervisors but the estimator should provide a robust estimate of kite position, velocity and orientation so that the appropriate control actions can be calculated. The performance goals to be achieved are:

- Kite stabilized at zenith for > 1 min.
- Figures of eight flown at constant line length for > 1 min.

Procedures

Time schedule

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Contents

Task i

Introduction vii

1 Kite Power in General and the Swiss Kite Power Project 1

2 IMUs 2

2.1 Centrifue Test . . . 3

2.1.1 Set-up . . . 3

2.1.2 Result . . . 3

2.1.3 Conclusion . . . 3

3 State Estimation 4

3.1 Basics of the Extended Kalman Filter . . . 4

3.2 State Estimation Model . . . 4

3.3 Sensor Estimation Model . . . 4

3.4 Covariances, Outage . . . 4

4 Results - Vicon Test 5

4.1 Set up . . . 5

4.2 Evaluation . . . 5

4.2.1 short vs long radius . . . 5

4.2.2 Outage and Sensor rate . . . 5

4.2.3 Pixhawk vs Xsens . . . 5

5 Conclusion 6

List of Figures

Introduction

Bla Bla Bla

Chapter 1

Kite Power in General and the Swiss Kite Power Project

Chapter 2

IMUs

For estimating the kite's state measurements from different sensors are needed. In so called inertial measurements units (IMU) several sensors are embedded. The most important difference between the the IMUs are in what sensors are embedded, with which rate do they provide the data, what is their range and sensitivity and how much signal processing is already done by the IMU. The Swiss Kite Power Project has the following options of IMUs to choose:

MTi-G The MTi-G development kit is a commercial product from the Dutch company Xsens. The unit has an accelerometer, gyroscope, magnetometer, pressure sensor and GPS with antenna included. It exist two output data formats. It can be chosen wether the output is raw data or calibrated data. The calibrated data from the sensors without GPS gives the data in $[m/s^2]$ and takes a offset calibration test into account. In addition to that is the GPS data processed with an Extended Kalman Filter in the calibrated output mode.

PX4 The PX4 is a open-source/open-hardware IMU used and developed by the PIXHAWK Project of the Computer Vision and Geometry Lab of ETH Zurich. The unit contains a temperature and pressure sensor, an accelerometer, a gyroscope and a magnetometer. The IMU additionally provides a counter for each sensor output. The output of the sensors is raw data. In the estimation algorithm(âĂę....label estimation chapter âĂę....) only the embedded accelerometer a BMA180 from Bosch (âĂę..DataSheetAppendix.....), the gyroscope a L3GD20 from STMicroelectronics (âĂę..DataSheetAppendix...) and the magnetometer a HMC5883L from Honeywell (âĂę.DataSheetAppendix...) is used.

x-IMU The x-IMU is a product of the company x-io Technologies. It has as well a temperature sensor, a accelerometer, a gyroscope and a magnetometer. The setting of the x-IMU was done by the FHNW. It provides only raw data. The data sheets of the sensors can be found in the (âĂę..APPENDIX.....).

2.1 Centrifue Test

There are several performance requirements on an IMU installed on a kite. One of them is the dependency on g-loads because on a kite several g loads can appear. Therefore a centrifuge test was carried out in corporation with the Fachhochschule Nordwestschweiz (FHNW)

2.1.1 Set-up

Set-Up The setting of the centrifuge is described in (âĂę..Figure.....). It is provided by the FHNW. A arm is rotated by a motor. The IMUs are set into a box at the end of the arm. The sensors are put next to each other to have the almost the same measurements in all sensors. The Box can be seen on the picture in (âĂę.Figure....). Obviously is the motion of the box describing a circle with a radius (he distance between the center and the center of the box) of $0.75m$. The motor is able to rotate the arm with a velocity of about $10m/s$. With formula $a = \omega * r^2$ we get maximum acceleration of about $8g$. There is no software for the data collection of the measured velocity implemented. Therefore we have no ground truth to compare the sensor data with. The motor is driven in order to have 5 steps between $1.62g$ and $7.8g$ ($ca.1.6g; 2.4g3.7g; 5.4g; 6.9g; 7.8g$) of centripetal acceleration. The PX4 and Xsens are connected together. Both, the PX4 and the Xsens measurements are written on the SD card which is attached on the PX4 Unit. The timestamp is taken from the GPS clock for the Xsens as well as for the PX4 sensor data at the time when they are written on the SD card. This results in easy and accurate synchronization between the two IMUs. To get the time synchronized with the third IMU, the x-IMU is synchronized to the computer's time. Additionally the 3 sensors are hit for having a estimation of how accurate the synchronization is.

2.1.2 Result

The raw data from the x-IMU is scaled by Raphael Mueller bringing it in the common units m/s^2 for the accelerometer, deg/s for the gyroscope and gauss for the magnetometer. The PX4 was set by the group of the PixHawk Project. How the output of the sensors have to be scaled to bring them in the required units is shown in (âĂę.table...). The scale factor describes by how much the output has to be multiplied to get the data converted in the units described in 4th row.

2.1.3 Conclusion

All IMUs work in the same range of noise level. With an increasing rotational velocity and therefore a higher centripetal acceleration, the average error is increasing in all sensors, except in the magnetometer. There could not be found a noise acceleration dependency. In a next experiment also the recording of rotational velocity should be carried out in order to generate a ground truth to compare the it with the IMU datas. It can then be made some more observations to compare the quality of the sensors with each other. Finally the sensitivity of the accelerometer of the PX4 unit should be set in a way to be able to observe the whole range or the applied and tested centripetal acceleration.

Chapter 3

State Estimation

3.1 Basics of the Extended Kalman Filter

3.2 State Estimation Model

3.3 Sensor Estimation Model

3.4 Covariances, Outage

Chapter 4

Results - Vicon Test

4.1 Set up

4.2 Evaluation

4.2.1 short vs long radius

4.2.2 Outage and Sensor rate

4.2.3 Pixhawk vs Xsens

Chapter 5

Conclusion