DOI 10.5162/ettc2022/9.3

Aircraft Maneuver Prediction with Machine Learning Applications

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Abstract:
The flight tests are an important phase of aircraft development programs. Currently, parameters of manned or unmanned test flights are analyzed by the test engineers. Maybe the process is still best choice for the reliability concerns, but on the other hand it is time consuming. So we want to propose flight maneuver predictor with using Machine Learning techniques. For this purpose, a collected dataset of a fixed-wing propeller aircraft is used. A machine learning model was created that can predict seven different maneuvers using the gathered data. During flight test every test maneuver's start and stop time tagged and labeled as test points by the flight test engineers. These labels are Takeoff, Landing, LSS, Phugoid, Loop, Wind Up Turn, and Aileron Roll. After gathering data, preprocessing is performed such as fixing row size of all attributes by timestamps. Also some other attributes which had less frequent data than the others reproduced. For the creation of prediction model, support vector machine (SVM) applied. Overall prediction score of the model is 0.90.

Key words: aircraft, maneuver prediction, machine learning, support vector machines

1. Introduction

The aerial vehicles are one of the biggest innovations in human history. After the development of plane and other aerial vehicles, humans rapidly started to use them in many areas such as surveillance, rescue, transportation, military etc. Along with these developments, flight test phases began to play a major role in the development of aircraft. During the flight test phase even the high-tech and other vehicles need some traditional methods to achieve completely success; therefore, the main problem starts with the test process. In aerospace every aircraft should be validated by professionals to be acceptable to fly [1]. Also some discrepancies of the aircraft can't be observed by bare-eyes even that the observer is professional. Thus, the flight test engineers must rely on the parameters displayed by the software and analyze those parameters. Flight tests are performed on varying flight conditions in order to address possible discrepancies. Furthermore, some of the test conditions need to be repeated over and over to evaluate the aircraft. Flight tests generally runs in campaigns. There are different types of flight test campaign such as experimental, certification, product delivery. In experimental flight tests, the engineers create a campaign that requires necessary maneuvers. After conducting maneuvers, analyses are performed by different aspects. Flight test phase of an aircraft can be a challenging issue for all types of aerial vehicles due to its risk of injury or worse possibilities. Risk management has to be done and flight tests must be performed in the safest way with the minimum number of sorties. To improve efficiency, automatic recognition of maneuver is crucial to recognize the maneuver and determine its accuracy. In the literature, many methods have been proposed for flight trajectory estimation, although they do not fully overlap with this issue. Most of this methods used for predicting trajectories of commercial aircrafts. To the best of our knowledge, there is no specific study on this subject in the literature. Machine learning, deep learning methods are proposed [2], [3] to predict the trajectory of the aircraft. In the past, the mathematical methods were used to predict the trajectory but with the growing effect of machine learning and deep learning methods, mathematical methods lost their place and they became complementary factors in deep learning and machine learning methods. The main motivation of the paper is related to solve the problem of predicting maneuvers. We want to contribute test phase of the aerial vehicles by using machine learning that predicts maneuvers automatically. By applying this, the results of the predictions will give the researchers new perspective of test scenarios and help them to complete the flight test campaign much faster.

In this study, we propose a novel Machine Learning based maneuver prediction method that can predict the maneuver between 7 different maneuver set, which are Takeoff, Landing, LSS, Phugoid, Loop, Wind Up Turn, and Aileron Roll. Another difficulty in this article is that the maneuvers we are trying to predict are acrobatic, complex so they are difficult to predict. As mentioned earlier in this article, the maneuvers we are trying to predict are those with acrobatic features rather than the maneuvers has stable parameter changes such as climbing, cruise, or descending maneuvers.

The rest of the paper is organized as follows. In the section 2, the related works are given. In the section 3, the maneuvers and data preparations are described. In section 4, we introduced the flight maneuvers prediction. In section 5, experimental setup and results are given. Finally, section 6 concludes the report by listing future directions.

2. Related Works

This section presents the related works that used in the aerial vehicles. Even there are similar studies, we would like to inform readers that there is no maneuver prediction study that aim to predict maneuvers in flight test processes. Moreover, we would like to remind you that the data was also gathered from a real propeller fixed wing aircraft.

The related works are generally stand for the classification of the maneuvers type. For example, NC. Oza et al. [4] used classification of aircraft maneuvers that was used for fault detection. Their main aim is to find automated fault detection approach. To apply this, they used method which is present mismatch between the current flight maneuver being performed and the result of prediction that consists classifier. Their dataset is collected under a controlled test environment. The detailed description of dataset is not given.

Another work which was released by M Al Mansour et al.[5],[6] tried to classify maneuver of moving vehicle by using logistic regression technique and analytical algorithm. In the first study, the researchers dealt with the problem using on-board MEMS IMU's data (three accelerometers and three rate gyros). The classification of the data is separated under the either discrete or continuous. The test data consists mixed between the simulation and real experiments of an UAV. The second study is a modified adaptive analytical algorithm that predict heading and attitude estimation. Different from the first study, their dataset consists fusion of IMU, magnetometers and the velocity data from GPS. They didn't use extra filter like Kalman Filter [7] to prevent noisy data.

Wang et al. [7] propose a pattern-recognition model to find a way of loads analysis from operational flight data for advanced aircraft. In the experiments actual F16, F18 flight data records are used. They firstly extract the maneuver from the flight data and determine the characteristics of maneuvers with a rule based application. After determining the maneuver they check the maneuver with the ones in the database. If the maneuver matches the maneuver from database then the output is successful. According to results, if there is enough number of identified maneuvers in the same type at database, new maneuvers can be determined after same preprocessing steps that used in the identified maneuvers.

3. Preliminaries of Flight Maneuvers Type and Dataset Preparation

This section presents maneuvers analyzing and dataset preparation which are needed for better understanding the whole dataset.

3.1 Maneuvers

Takeoff maneuver is the first maneuver of the flight. The aircrafts's landing gears and wheels are on the ground before maneuver. After engine got the power the take off, aircraft increases air speed rapidly. Also, Pitch angle will be increased after the wheels are on the air. The takeoff can be performed only once per flight. [9]

Landing maneuver is the last maneuver of the flight. In the landing maneuver, aircrafts ground speed decreases to zero. In addition, Pitch angle will be decreases until the limit. When the vehicle approaches the ground, pitch angle firstly has a small positive change then the pitch angle come close to zero. The land can be performed only once per flight.

The phugoid maneuver is a rippling movement in which kinetic and potential energy are traded. Each move takes about one minute. As the the altitude increases the airspeed decreases, and as the altitude decrease the airspeed increases. There is, however, little or no change in the load factor if the aircraft has a neutral pitch stability. (see Fig 1.) and this motion depends on the characteristics of the aircraft.

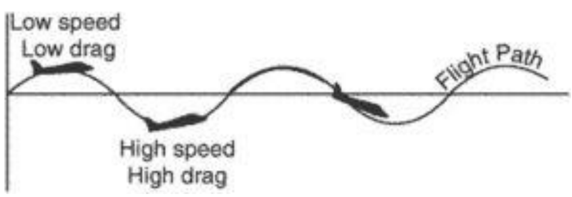

Fig 1. Phugoid Maneuver.

The loop maneuver is achieved by having the pilot pull the aircraft up and continue the pulling motion until a 360° turn is completed. (see Fig 2.). At the apex of this maneuver, the pilot will be upside down.

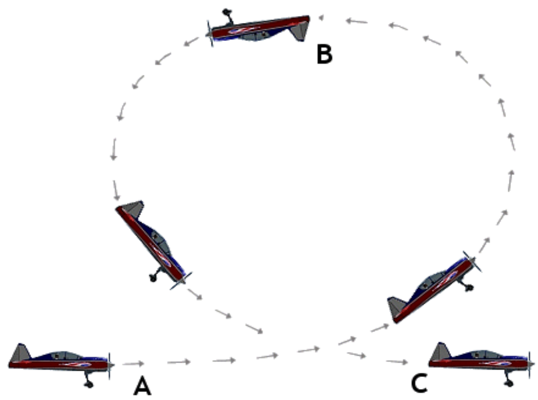

Fig 2. Loop Maneuver.

The Windup Turn maneuver is a mostly constant altitude turn with increasing angle of attack or increasing normal acceleration. During this maneuver, the steepness of the bank transfers some of the lift toward the direction of the turn. During this maneuver, the aircraft moves to the center of the earth and its weight remains the same, while the pilot increases the angle of attack to prevent the aircraft from falling [11].

The stability of an airplane in the longitudinal, or pitching, plane under constant flying conditions is known as longitudinal static stability. This quality is critical in deciding whether a human pilot can control the aircraft in a pitching plane without demanding undue concentration or strength. If an aircraft is longitudinally balanced, a modest increase in angle of attack will result in a negative (nose-down) pitching moment, lowering the angle of attack. A modest drop in angle of attack, on the other hand, will result in a positive (nose-up) pitching moment, causing the angle of attack to increase. In the LSS maneuver, the pilot gives command to change the aircraft’s angle of attack in a negative or positive direction and tests whether the aircraft has stabilized [12].

An aileron roll is a constant 360° roll about the aircraft's longitudinal axis. When properly executed, there is no visible change in altitude, and the aircraft finishes the maneuver on the same heading as when it entered. In the Aileron roll maneuver, the pilot starts from steady flight and steers the aircraft's horizon to a slight climb of about 10 to 30 degrees. When the aircraft begins maneuvering, it begins to lose lift. When the wings become upright, only a slight lift is generated from the fuselage and tends to lose altitude. The short ascent at the beginning will compensate for this loss and will enable it to reach the initial altitude. When the airplane is fully inverted, the increased pitching results in a greater angle of attack and allows the inverted wing to generate lift. After completing the roll, the pilot will need to ascend to return to level flight [13].

3.2 Dataset

In Turkish Aerospace flight test processes, flights are made for many maneuvers within the flight test campaigns for each aircraft. The maneuver data we obtained was created with the maneuvers selected from these flight test campaigns. The whole flights are performed under control of the skilled pilots and powerfull ground telemetry systems. Data grounded by telemetry over a real aircraft were used. Each of our maneuvers is labeled by flight test engineers. Thanks to our telemetry engineers and flight test engineers we didn't need to label the data after we gathered it. There are lots of different parameters in an aircraft with FTI configuration in it. We needed to select the specific ones in nearly 15000 parameters. We narrowed it down to 17 parameters to prevent overfitting and making model too complex than it should be. Because every flight has some characteristic values, if we use all attributes on the train part, the test part and results would be really unacceptable. These parameters are the accelerations, rates etc. We didn’t use the GPS data to prevent model to learn the GPS coordinates for a maneuver and make wrong predictions. We used 50 samples for each maneuver in training and 8 samples for each maneuver in test. In total 350 sample for training and 56 sample for test.

3.3 Preprocessing the Dataset

In the preprocessing phase, our aim is to reduce dataset with the related ones. In addition to this, we reproduce the missing and insufficient data that produced in low frequency. After trying different approaches, we chose augmenting the data. After augmentation we fix the row size of the dataset. After the fixing row size of dataset, we added 7 binary columns as target columns.

At first sight the data was noisy and had different sample rates for each different files that the sensors made. We needed to resample the data to a fixed sample rate. Some of the files had 49000 rows and some of the files had only 250 rows. That was a major problem for our situation but it’s always a problem that the people who works with sensor data to solve. The final solution to solve this problem was the interpolation. But before that we tried to solve this problem by hand and try to avoid the

DOI 10.5162/ettc2022/9.3

rounding problems that interpolation gives. In the end due to the timestamp problems we solve this sample rate problem with interpolation. After interpolation, as can be seen in the Fig. 3 and Fig. 4 the output that the sensors give did no change. As can be seen at Fig. 3 to Fig. 4 the interpolation made just slight changes at the data that we can ignore while working on our project.

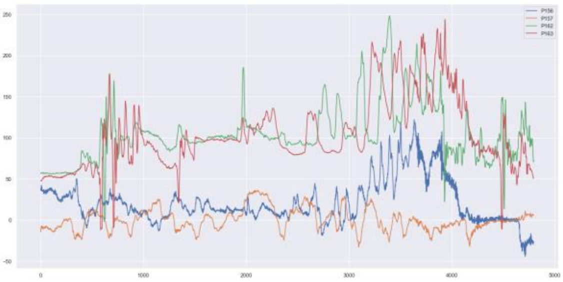

Fig 3. Not augmented data gathered direct from the sensors

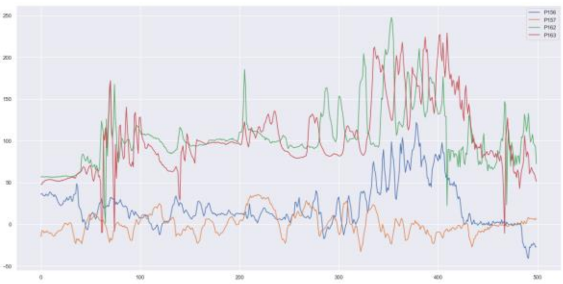

Fig 4. Augmented data.

After this we finally had a dataset we can work on but with slight problems. The dataset was spread over 400 different files. We concatenated the dataset into per maneuver and add the binary classifier as takeoff or landing or any other class.

4. Flight Maneuver Prediction

In this section, evolution of our model is presented.

After preprocessing stage of the data finished, we had nearly 400 different files that each one has the all data from one particular maneuver. To predict the maneuver of aircraft we use SVM One-Vs-Rest classifier [14]. Originally SVM only works for binary classification problems but in our situation we had 7 different maneuvers to predict. To predict that we use the One-Vs-Rest classifier. Before starting to work with the files first we need to fix some other problems like scaling and vectorising the data [15]. The data is splitted according to the flight numbers and the maneuvers. Firstly we interpolate the data that distributed in different files. Reason of this interpolation was that the row number of each maneuver tag must be equal when we fed data to model. If row numbers are not equal then one has the most row number will probably dominate the model and made model memorize itself rather than learn. To do so we did the interpolation and set the row size to 500 for each maneuver. After interpolation there was one last thing to do before send data to train. We used MinMaxScaler to scale the interpolated data. With that we shrink the range of data between 0 and 1. The advantage of using this scaler was mostly we don't want the information loss in the data and we want to make all parameters in dataset in the same range to prevent one parameter to dominate the other ones. After scaling we send the data to train. In the training phase firstly we vectorized every single different maneuver. We did that because we need to use SVM and to use SVM with time series data needs reshaping. Before reshaping we have nearly 400 different files with 17 columns and 500 rows. After reshaping and vectorising, the shape of the data changes as in Fig. 5. After this we had a data frame for each maneuver –in our case this maneuvers are "Takeoff", "Landing", "LSS", "Phugoid", "Loop", "Aileron Roll", "Wind Up Turn" -contains 50 rows –this rows stands for each flight- and 8500 –to get this size 500*17- data in each row. While vectorising data we split the data and target matrix.

After doing all interpolation, scaling, normalization and vectorization operations the data is ready to train. As we mentioned before we used SVM as model and "One Vs RestClassifier" as approach. We use 50 samples per maneuver as train and 8 samples

Fig 5. The reshaping process of the data

per maneuver as test data. The results are quite convincing and good for a predict like this as you can see in Experimental results. Table 1.

5. Experimental Results

At the beginning of the experience, experimental results are generally close to 1.0 overall score. This problem indicated to overfitting problem. We were using almost every attribute of the flights. Thus, we had to move our model to a more generalized one. Then we wanted to catch the sweet-point of the obtained attributes. With generalization and feature engineering phases we finally find the sweet point that doesn't overfit and gives us the pretty good results.

Experimental Result(ER)	Accuracy	Presicion	Recall
ER-1	0.90	0.90	0.91
ER-2	0.89	0.89	0.91
ER-3	0.89	0.90	0.90
ER-4	0.87	0.88	0.88

Table 1. Model Experimental Result Values.

As can be seen in Table 1, each experimental result gives pretty close results to each other. Four different ER refers to four different test datasets of maneuvers.

6. Conclusion and Future Directions

In this paper, a new technique for flight test data processing is introduced. This work present the opportunities on the test field in the many areas of flight test phases by using Machine Learning techniques to validate system. The results show the success of the method.

As a result of this paper, we have seen that machine learning methods can help both test engineers and developers in every field during and after flight tests. By using these methods, the accuracy of the maneuvers made in the tests can be validated, it can be determined whether the test has been successful or not, or the outputs of the method we recommend can be used in the analysis after the test.

In the following process, our first goal will be to increase the number of maneuvers in the model and turn the model into a machine learning model that detects which maneuver the aircraft is in from among more maneuvers. As the number of maneuvers checked in the SVM method increases, SVM models slowing down will be a problem for us. We plan to overcome this problem by using hybrid systems or by switching to deep learning methods. Our long term goal is to create a model that can predict which maneuver the aircraft is in during the test by making this model prepared for real time prediction. With the help of this method we are aim to create a learning model that can create a virtual pilot with the abilities to do the predicted maneuvers and reduce the workload on the pilot in flight.

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