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UNMANNED AERIAL VEHICLE FLIGHT DATA PROCESSING BY SPLINE APPROACH

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Abstract. *The article considers the reasons of UAV information flow fault during the flight. An importance of UAV data flow monitoring and recovering was proved. An existing data recovering methods were discussed. The advantages of spline interpolation method for UAV parameters processing were described. The results of fault recovering simulation for real UAV position data using spline approach were demonstrated.*

Keywords: B-spline; Data Processing and Recovering, Information Flow Fault; Spline Interpolation; Unmanned Aerial Vehicle.

1. Introduction

Nowadays, unmanned aerial vehicles (UAVs) operate in real missions with various levels of autonomy. They are used for search, rescue, monitoring, collaborative indoor and outdoor surveillance and protection. Moreover, UAV applications include firefighting, some level of policing, support in case of natural disasters, remote sensing, scientific research, and geographical surveying. It is commonly acknowledged that the development of UAVs gives the possibility to perform missions that are too dull, dirty or dangerous for humans.

During the flight, a variety of events may affect the operation of UAVs. These include faults, or malfunctions, and failures, or complete breakdowns, in flight-critical components, platform damage, faults and failures in intervehicle information flow, anomalous behaviors or extreme weather. Removing the human from some of the flight control tasks and replacing by software systems is a challenge that addresses safety implications.

When UAVs are flying, their onboard systems exchange the necessary information via the communication network. Suppose one of the actuators of a UAV develops a fault. If the control system of the faulty UAV is not equipped with some form of robustness to fault, or if the control system is not capable of providing sufficient recovery to the fault, the vehicle may lose stability and exhibit an unpredictable behavior.

Faulty aerial vehicles fail to fulfill mission objectives, and represent a danger to humans.

Thus, continuous UAV data flow monitoring has an extreme importance and is a key challenge for predictive control.

2. Analysis of research and publications

There are different approaches for data recovering in case of UAV information faults [1-3]. Existing methods of data recovery allow choosing the most appropriate one considering input data, technical possibilities and aims of research.

The majority of researches divide the recovery methods into the following groups: method of incomplete objects exclusion; methods of data completing; methods of weighing and methods based on modeling [1].

3. Purpose of work

Very often researches have to deal with the problem of missing data processing in data arrays. The reasons that lead to the missing data, is the inability of data obtaining or processing, its distortion or concealment.

Most of the known methods of data analysis can not process such information, therefore it is necessary to complete and recover missing data. In case of UAV that is a dynamic system and has a variety of flight data the most of existing methods con not meet the requirements of data recovering in real time.

Therefore the main purpose of the article is choosing the most appropriate approach for UAV data processing and recovering.

4. Analysis of data recovering methods

In the common way data recovering is a flexible method of solving the tasks with missing data during arrays processing.

There are four groups of data recovering methods:

1. Methods of incomplete objects exclusion. In case of absence of some object values a simple solution is to remove such incomplete object of analysis and to process data without missing data. This approach is easily implemented and can be satisfied with a small number of missing data. However, sometimes it causes serious shifts and usually is not very effective.

2. Methods of data completing. Missing data are filled and received "completed" data is processed by conventional methods. To receive correct conclusions it is necessary to introduce modifications into standard methods that distinguish filled and real data.

3. Methods of weighing. Conclusions by sample survey with missing data are usually built on the weight of the plan, which is inversely proportional to the probability of selection, but these methods change the weight to take into account missing data.

4. Methods based on modeling. A wide class of methods based on constructing a model of missing data formation. Conclusions are received by likelihood function, which is based on fairness conditions of the model with parameter estimation by methods with maximum likelihood type. The advantages of this approach are that it is flexible and allows reject the methods developed for specific cases.

The methods of missing data recovering in sample surveys are the following:

1. Filling by the average values of the existing in the sample. Average values can be formed within the groups is similar groups formed for weighing procedures. By this approach, filling the average leads to estimates similar to the estimates by the weighing method at a constant sample weights in the weighting classes.

2. The procedure of missing data filling with the selection can be generally described as a method in which the substitution is selected for each missing value estimating the distribution, in contrast of filling the missing data by average when average distribution is substituted.

3. Filling without selection. Missing data is filled by constant value from an external source, such as the value of the previous observations of the same survey.

4. Replacement – method of missing data processing during the data collection phase in the survey. It is based on the replacing of the object with the absence of response to another object that is not included in the sample.

5. Filling by regression based on the replacement of missing data by value we substitute in filling the regression with the remainder in the sum reflecting the uncertainty of the predicted value. Filling by the average can be considered as a special case of filling by regression [2].

6. The method of spline interpolation is a mathematical interpolation method, showing good results.

7. At the methods of multiple filling a missing data is filled by multiple values. The main advantage is that they overcome the disadvantages of single filling methods in the sense of the greater spread of estimation variance.

8. Composite methods are based on the ideas of several methods.

9. ML-assessment – refers to the category of modeling methods. The peculiarity of these methods is the construction of a model of missing data generation, followed by the conclusions obtained on the basis of the likelihood function.

10. The use of factor analysis methods. There is no requirement of a priori fill the missing data, there is a need for pre-normalization of data and existing of requirements of factor analysis.

11. The use of cluster analysis methods. Its application is not based on any probabilistic model, but to estimate the properties in statistical terms is not possible.

12. Neural network methods as one of the approaches to the data recovery are used. The main conditions of this method application are probabilistic relationship between data, the number of existing observations, which recover missing data shall not to be small.

5. Spline approach for data processing

Spline approach is a universal mean of parameters processing and recovering by computer-based techniques. Spline is continuous and defined on fragments function S, which consists of fragments that are functions of the same species and docked in a special way. Points of docked fragments are called spline nodes.

The basic condition for joining the fragments is continuity of values and derivatives at the docked points.

Spline approach has a row of advantages:

First, good differential, approximation and algorithmic properties.

Second, experimental information has a discrete nature (for example, the values of a process at different times) using splines can be converted to a continuous form recorded as a function of approximately reflecting the real process.

Third, the experimental data, no matter how they are obtained, always have some errors. Using such data as input for the various calculations can lead to significant distortion of the result. Smoothing in many cases allows transforming the initial information to a form suitable for the further use.

The advantages of spline interpolation include high processing speed of computational algorithm as spline is a piecewise polynomial interpolation function and at the same time data is processed by a small number of measurement points belonging to the fragment under consideration at the moment.

Investigation model can be represented as a regression model at the interval [0, T] with k parameters of observation: $\vec{y}_i = \vec{S}_0(t_i) + \vec{E}_i,\ i = \overline{1,n}$

where $\vec{S}_0(t) = (S_0^{(1)}(t), \ldots, S_0^{(k)}(t))^T$.

The components $S_0^{(j)}(t)$ are cubic C^2 –smooth splines with known nodes

$\tau_0 = 0 < \tau_1 < \ldots < \tau_N = T$.

The moments of observations are ordered:

$0 = t_1 < t_2 < \ldots < t_n < T$, and $t_n > \tau_{N-1}$.

Random errors $\vec{E}_i$ are unbiased: $\mathrm{E}\vec{E}_i = \vec{0},\ i \geq 1$

where E-mathematical expectation.

One of the most suitable spline curves is B-spline. It possesses a good interpolation and approximation properties for UAV data processing and recovering. Also it guides through basic points which provides the possibility of precise fitting.

B-spline interpolation is grounded on data separation into several intervals (N) with the corresponding interpolation at each interval. Resultant curve is a sum of splines at each interval. In a common way B-spline curve can be represented by the following formula:

$$S(t) = \sum_{j=1}^{N} B_j(t) x_j,\ 0 \leq t \leq T,$$

where Bj(t) – B-spline for specific time t; xj – control points coordinates.

B-spline functions can be of different order and can be calculated using the Cox-De Boor relations [4]. There are a lot of challenges when it is necessary to estimate multi-parametrical data simultaneously. B-spline interpolation in such case can applied in a simple way by adding new control points and inserting B-splines into main formula.

One of the most important problems in spline interpolation is intervals selection. Typically interpolation intervals are uniformly distributed and the task is to estimate the optimal grid step. But for more precise fitting is suitable to use non-uniformly distributed intervals. In that case the most appropriate methods of interval calculation are chord length and centripetal methods [4].

During the flight UAV transmits a set of flight data. In the common way it includes all sensors data. One of the most valuable is UAV position information in specific coordinate system. An UAV position information fault is one of the major hazards during the flight.

During the modeling real data of UAV flight was used. The flight was performed in automatic mode with neglible wind component by pre-planned trajectory of “eight” form.

Data is represented in local NED coordinate system. Coordinates are represented as a distance from the starting point in meters on fig.1-3 indicated by stars. Z axe has downside direction.

During fault simulation data for some short time has been absent. Fault period was chosen for the moment from 128 s till 148 s of flight. Data of the fault period was recovered using spline interpolation. The results of recovering are represented on fig 1-3 by circles.

Spline interpolation errors of position data are represented on fig. 4. The maximum error value is less than 23 m.

6. Conclusion

During the flight UAV is a subject of information flow fault due to a lot of reasons.

To guarantee flight safety the continuous UAV data flow monitoring has a primary importance for predictive control. Spline approach is a universal mean for continuous UAV flight data processing and recovering. The results of fault recovering simulation for real UAV position data indicate quite accurate results (fig.4) and prove the usage of spline approach for UAV flight data processing

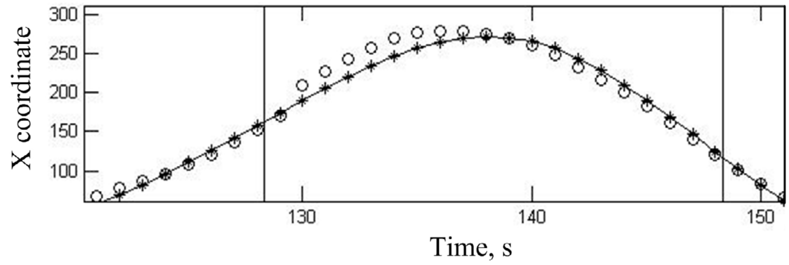

Fig. 1. X coordinate representation

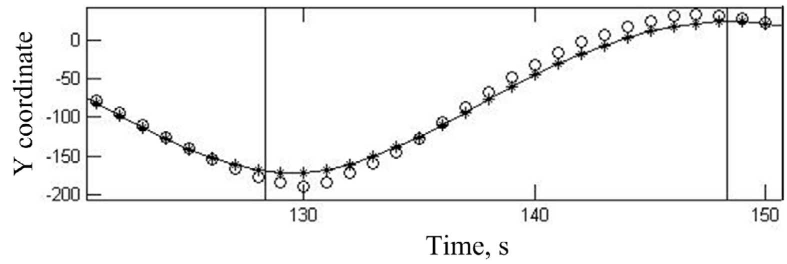

Fig. 2. Y coordinate representation

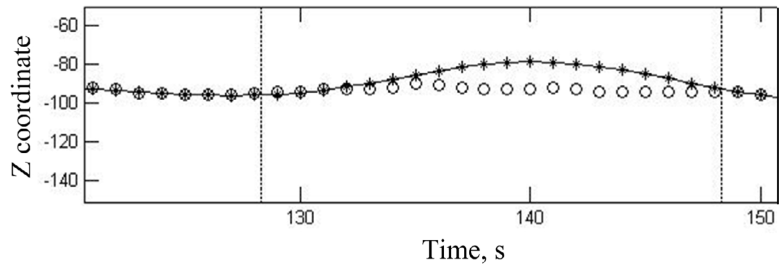

Fig. 3. Z coordinate representation

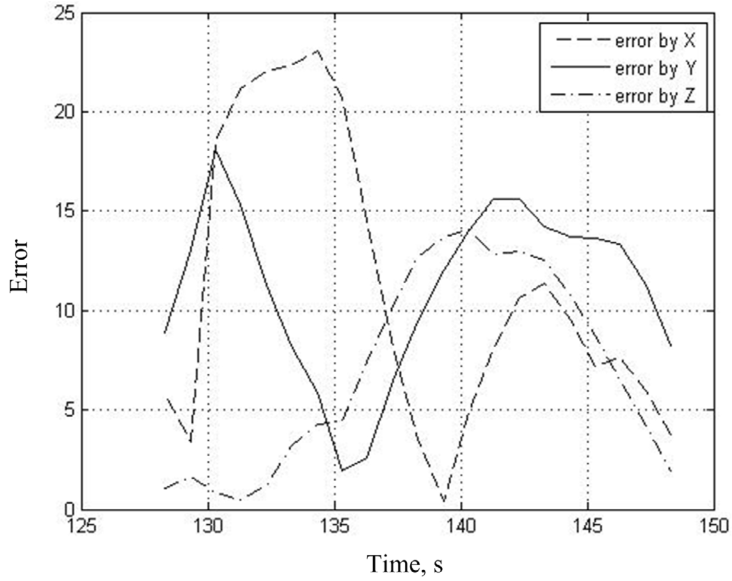

Fig. 4. Spline interpolation errors of position data

References

[1] *Little, R., Rubin, D.* Statistical Analysis with Missing Data. Wiley-Interscience, 2002. 408 p.

[2] *Draper N., Smith H.* Applied regression analysis. Wiley-Interscience, 1998. 706 p.

[3] *Zloba, E., Yatskiv, I.* Statistical methods of reproducing of missing data. Computer Modelling & New Technologies, Riga, 2002. P.51-61 (in Russian).

[4] *Frank, A.* Interpolation of 3D Surfaces for Contact Modeling. University of Twente, The Netherlands, 2005. 51 p.

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В. П. Харченко[1], Н. С. Кузьменко[2]. Обробка польотних даних безпілотних літальних апаратів з використанням сплайн-функцій
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Статтю присвячено актуальним питанням моніторингу та відновлення польотних даних безпілотних літальних апаратів (БПЛА). Розглядаються наявні методи відновлення даних, увагу зосереджено на використанні методу сплайнів. До переваг використання сплайн-функцій віднесено їхні диференційні та алгоритмічні властивості; можливість представити дискретні дані у неперервному вигляді, що дозволяє представити реальний процес; згладжування похибок експериментальних даних, що дозволяє їх подальшу обробку та використання. Представлено результати моделювання обробки польотних даних БПЛА з використанням сплайн-функцій. Під час моделювання використовувалися реальні польотні дані БПЛА, політ якого проходив в автоматичному режимі із запланованою траєкторією форми “вісімка”. Дані були представлені в локальній системі координат. Під час моделювання було застосовано метод сплайн-інтерполяції для відновлення даних для проміжку часу із втраченими даними.

Ключові слова: Безпілотний літальний апарат; Втрата інформаційного потоку; Обробка та відновлення даних; Сплайн-інтерполяція; В-сплайн.

В. П. Харченко[1], Н. С. Кузьменко[2]. Обработка полетных данных беспилотных летательных аппаратов с использованием сплайн-функций
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Статья посвящена актуальным вопросам мониторинга и восстановления полетных данных беспилотных летательных аппаратов (БПЛА). Рассматриваются существующие методы восстановления данных, внимание сосредоточено на использовании метода сплайнов для обработки и восстановления утраченных полетных данных БПЛА. К преимуществам использования сплайн-функций отнесены их хорошие дифференциальные и алгоритмические свойства; возможность представить дискретные данные в непрерывном виде, что позволяет представить реальный процесс; сглаживание погрешностей экспериментальных данных, что позволяет их дальнейшую обработку и использование. Представлены результаты моделирования обработки полетных данных БПЛА с использованием сплайн-функций. При моделировании использовались реальные полетные данные БПЛА, полет которого проходил в автоматическом режиме с запланированной траектории формы "восьмерка". Данные были представлены в локальной системе координат. При моделировании был применен метод сплайн-интерполяции для восстановления данных для промежутка времени с утраченными данными.

Ключевые слова: Беспилотный летательный аппарат; Обработка и восстановление данных; Потеря информационного потока; Сплайн-интерполяция, В-сплайн.

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