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Model-free techniques for tuning the parameters of automatic controllers

PhD Thesis – Summary

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The PhD thesis entitled „**Model-Free techniques for tuning the parameters of automatic controllers**" is focused on implementing and improving model-free algorithms exemplified by Model-Free Adaptive Control (MFAC) and Model-Free Control (MFC) with experimental validation on the twin rotor aerodynamic system (TRAS). The thesis is structured on five chapters as it follows.

Chapter 1 presents the approached topic along with the motivation of the research. Next the main objectives of the thesis are presented as it follows:

- The main objective of this thesis is to automatically determine the parameters of the model-free algorithms. This objective appeared in the initial moment of the state of the art research (the autumn of 2014), when the problem of choosing the best values of the initial controllers was placed, because the initial values of the model-free controllers were determined heuristically both in MFC and MFAC cases.
- The second objective of the thesis is to experimental validate the model-free techniques. According to the author's knowledge, the experimental validations presented in the following capters are the first world wide applications of the MFC and MFAC algorithms on the twin rotor aerodynamic system laboratory equipment.

The end of the first chapter gives a brief overview of the thesis next the twin rotor aerodynamic equipment is presented, a two degrees of freedom equipment with two inputs and two outputs, where the vertical motion of the TRAS induces disturbances on the horizontal motion while the azimuth motion to pitch coupling induces negligible disturbances. All the experimental validations presented in chapters 2, 3 and 4 were performed on this laboratory equipment.

At the beginning of **Chapter 2** a brief overview of the Model-Free Control (MFC) algorithm is presented. Next a state of the art research is performed in order to highlight the main advantages and disadvantages of the algorithm, preparing the following four subchapters in which the MFC algorithms are detailed and then experimental validated on the twin rotor aerodynamic system laboratory equipment. Three subchapters are dedicated to MFC hybrid techniques versions:

- The first hybrid technique proposed is achieved by mixing the MFC technique with a Linear Quadratic Regulator (LQR) denoted MFC-LQR. Three goals are pursued:
  1. the optimal allocation of the parameters of the MFC controllers (that by case may be numerous),
  2. a systematically assessment of the performances of the control structure with MFC controllers, and

3. ensuring the stability of the control structure by imposing stability restrictions, by using the mathematical models of the controlled system. The MFC-LQR hybrid technique is experimental validated on the twin rotor aerodynamical system laboratory equipment.

- Model-Free Control-Virtual Reference Feedback Tuning (MFC-VRFT) is the second hybrid technique and it is proposed by achieving two goals:
  1. optimal tuning of the MFC controller parameters,
  2. ensuring the stability of the control structure. The new MFC-VRFT mix is validated through simulation results by using the detailed mathematical model of the twin rotor aerodynamical system equipment.
- For the third hybrid technique mix, called Model-Free Sliding Mode Control (MFSMC), two MFSMC implementation approaches are proposed by mixing the MFC with Sliding Mode Control (SMC), namely MFSMC1 and MFSMC2. The mix of data-driven and SMC techniques emerged due to applications that require control structures with superior control performances, and control algorithms specific to those techniques that have been developed by using the Lyapunov's stability theory. The new MFSMC1 and MFSMC2 hybrid techniques are experimental validated on the twin rotor aerodynamical system laboratory equipment.

The end of Chapter 2 highlights the conclusions and the proposed contributions brought to MFC technique.

The theoretical results of the Multi Input-Multi Output (MIMO) case, proposed in Chapter 2 are applicable to nonlinear processes where the number of inputs is equal with the number of outputs.

In the first part of **Chapter 3** a brief description of the Model-Free Adaptive Control (MFAC) technique is presented. Next it is followed by the state of the art research in order to present the advantages and the disadvantages of the MFAC algorithms. The flowing three subchapters are dedicated to MFAC algorithms as it follows:

- The MFAC algorithms in Compact Form Dynamic Linearization (CFDL) version are described, and next experimental validated on the twin rotor aerodynamical system laboratory equipment.
- The MFAC algorithms in Partial Form Dynamic Linearization (PFDL) version are described, and next experimental validated on the twin rotor aerodynamical system laboratory equipment.
- In the next subchapter the Model-Free Adaptive Control-Virtual Reference Feedback Tuning (MFAC-VRFT) hybrid technique is proposed in order to automatically compute all initial parameters of the MFAC algorithm in the absence of some steps for systematical parameters determination. The new MFAC-VRFT mix technique is experimental validated on the twin rotor aerodynamical system laboratory equipment.

The conclusions and the proposed contributions brought to MFAC technique are highlighted in the last subchapter.

As in the previous chapter, the theoretical results of the MIMO case, proposed in the current chapter are applicable to nonlinear processes where the number of inputs is equal with the number of outputs.

Chapter 4 is dedicated to a comparative study between two model-free techniques, namely MFC and MFAC, and the Virtual Reference Feedback Tuning (VRFT) technique in order to determine which model-free algorithm designed in various ways ensures the best performances of the control structure for azimuth and pitch control of the nonlinear twin rotor aerodynamical system laboratory equipment. Three case studies are proposed:

- In the first case study the experimental validation of the MFAC-CFDL algorithms developed as MFAC-CFDL controllers is presented, the MIMO controllers are designed in two ways:
  1. as MIMO MFAC-CFDL controllers, for these algorithms the MFAC-MIMO acronym is used and
  2. as two Single Input-Single Output (SISO) MFAC-CFDL controllers that are running in parallel, for these algorithms the CFDL-2SISO acronym is used.
- In the second case study eight types of control structures with MFAC-CFDL, MFC and VRFT controllers in various combinations without applying disturbances are experimental validated as it follows:
  1. the MFC MIMO algorithm is designed as a MIMO controller, where the MFC-MIMO acronym is used,
  2. the MFC algorithm is designed as two SISO controllers that are running in parallel, where the MFC-2SISO acronym is used,
  3. the MFAC-CFDL MIMO algorithm is designed as a MIMO controller, where the CFDL-MIMO acronym is used,
  4. the MFAC-CFDL algorithm is designed as two SISO controllers that are running in parallel, where the CFDL-2SISO acronym is used,
  5. the MFC SISO algorithm is applied to azimuth control and the CFDL-MFAC SISO algorithm is applied to pitch control, both algorithms are running in parallel, where the MFC_a-$CFDL_r$ acronym is used,
  6. the MFAC-CFDL SISO algorithm is applied to azimuth control and the MFC SISO algorithm is applied to pitch control, both algorithms are running in parallel, where the $CFDL_a$-MFC_r acronym is used,
  7. the VRFT MIMO algorithm is designed as a MIMO controller, where the VRFT-MIMO acronym is used,
  8. the VRFT algorithm is designed as two SISO controllers that are running in parallel, the VRFT-2SISO acronym is used.
- In the third case study the eight control structures with MFAC-CFDL, MFC and VRFT controllers in various combinations used in the second case study are experimental validated with applying disturbances in order to establish which of the model-free algorithms manages to provide the best performances in controlling the azimuth and the pitch position of the TRAS equipment, the quantification of the azimuth influence on the pitch and the quantification of the influence of the pitch on the azimuth.

Chapter 5 contains the final conclusions, personal contributions, the fact that the obtained results from this thesis are supported by **22** published papers where the author of the thesis is the first author of 10 of the 22 papers. The published papers are grouped according to the international databases which they are indexed:

- 5 papers published in journals with impact factor indexed in Clarivate Analytics Web of Science (with one of the previous names ISI Web of Knowledge), with a cumulative **impact factor of 13.792** according to Journal Citation Reports (JCR) published by Clarivate Analytics in 2017;

- 2 papers published in journals without impact factor indexed in Clarivate Analytics Web of Science (with one of the previous names ISI Web of Knowledge);
- 9 papers published in proceeding volumes indexed in Clarivate Analytics Web of Science (with one of the previous names ISI Web of Knowledge);
- 6 papers published in proceeding volumes indexed in international databases as IEEE Xplore, INSPEC, Scopus and DBLP.

The published papers have received a sum of **38 independent references** (excluding auto-references and all co-authors references). **The cumulative impact factor of the independent references is 60.936** according to Journal Citation Reports (JCR) published by Clarivate Analytics in 2017. The references are grouped according to the international databases which they are indexed:

- 23 references indexed in Clarivate Analytics Web of Science (18 in journals and 5 in proceeding volumes);
- 5 references indexed in international databases as Scopus, IEEE Xplore and DBLP;
- 10 references indexed in Google Scholar.

The end of the thesis highlights the subsequent research directions that the author of the PhD thesis will focus on.

The thesis contains three appendixes as it follows:

- Appendix A1 contains the discrete time implementation of the simplified nonlinear mathematical model of the twin rotor aerodynamical system laboratory equipment as a function.
- Appendix A2 contains the MIMO discrete time implementation of the MFC algorithm.
- Appendix A3 contains the SISO discrete time implementation of the MFAC algorithm in CFDL and PFDL versions for the pitch control when the azimuthal motion is locked.

The PhD thesis contains:

- 129 pages,
- 45 figures,
- 11 tables and
- 138 state of the art reffrences.

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