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Review report on PhD thesis of Ing. Filip Svoboda

To whom it may concern,

In conformity with the requirements for awarding a Ph.D. degree in the Czech Republic, I, Alexander Schirrer, senior scientist at TU Wien, Institute of Mechanics and Mechatronics, may hereby act as a reviewer of the Ph.D. thesis of Ing. Filip Svoboda entitled "Structured Control Laws for Flexible Wing Concepts". The thesis particularly offers a methodological treatment of decentralized control designs for large-scale systems whose subsystems are mutually coupled, as is the case in flexible structures. This approach is further developed in the context of an aeroelastic morphing wing control problem and compared to other, centralized reference control strategies. My account of the thesis content and quality, as well as my recommendation are stated in the following.

Relevance of the thesis
The thesis topic is relevant in both a methodological sense as well as in the important class of flexible structure control applications. Globally, the morphing wing developments address aviation transport efficiency and thus help reduce the transport sector's climate impact. On a more fundamental level, the extension of large-scale system control methods via appropriate decentralized design approaches have potential benefit in many different application domains.

Fulfillment of main objectives; Main results and contributions
The thesis sets out to address three main goals:

1. **Easily scalable decentralized control algorithms for active damping of mechanical flexible structures** should be developed. The candidate is second author of a corresponding journal article which proposes a low-complexity decentralized active damping design approach for one-dimensional mechanical flexible structures.
2. The developed control algorithms should be **extended to address aeroelastic problems**, particularly to improve flutter resistance. In the candidate's second journal article, in which he is first author, this goal is addressed by developing decentralized control laws for large-scale systems with inherently coupled subsystems.
3. The developed methods should be **applied to and demonstrated for morphing wing concepts**. In the candidate's third journal article, the decentralized control approaches are extended and applied in the context of morphing wing aeroelastic control.

Two main contributions given by this thesis stand out: The first contribution is the development of a systematic method to design decentralized control laws for large-scale systems in which the subsystems are coupled physically. In literature, no large-scale design algorithms for a systematic treatment of such inherently coupled systems have been shown yet, so the thesis fills an important research gap. The second contribution is the deployment of these control designs to a basic morphing wing aeroelastic control problem, successfully evolving the methodology to a realistic setting. Summing up, the three goals are well-aligned and successfully solved in the thesis, backed by the three journal articles.

Appropriateness of the methods
The thesis appropriately combines the graph-based information topology modeling approach commonly found in large-scale control system design with the specifics of the considered class of control problems, particularly the flexible structure characteristics and the inherent spring/damper coupling between system dynamics unit cells. It does synthesize important new methods and tools to enable and extend solutions to such control design problems. Hence, the main goals and contributions are developed with an appropriate basis of methods and tools.

The thesis is structured into four Chapters. Chapter 1 introduces the considered large-scale control system context and relates it to aeroelastic wing structure control applications. It lists the thesis goals, outline and contributions. Chapter 2 – 4 reproduce the three journal articles aligned with the mentioned goals.

One point of critique is that the thesis structure feels incomplete. The introductory outline mentions wing hardware testing and measurement campaigns which are not revisited later on in the thesis, and no concluding discussion is given which would relate the thesis goals to the achievements and which would point to future research directions.

Also, as a second criticism, the presented comparisons of the proposed decentralized control designs with reference control laws in Chapters 2 – 4 (LQR or $\mathcal{H}_\infty$ designs) are not sufficiently detailed in their design parameters to be able to reproduce the thesis results. These issues do not invalidate the thesis' findings, but with these issues solved, the thesis could have provided a significantly better usability for the scientific community.

Importance for the further development of science
The scientific level of the thesis is good and appropriate, and it delivers important results both methodologically (large-scale control design) and in the application of flexible structure damping and morphing wing aeroelastic damping augmentation.

The thesis scientific quality is sufficient for the usual international requirements for Ph.D. theses: the thesis is supported by 3 directly related journal articles in which the candidate is second author in one and first author in the other two articles. The thesis furthermore lists 7 related conference papers in which Ing. Svoboda is listed as first author, and 8 further conference papers which he co-authored. This widens the scientific stance of the thesis topics, although it would have been desirable to have these conference papers related to the thesis topic, as they complement the exposition in the thesis and provide a broader picture.

Satisfaction of conditions of a creative scientific work
In total, Ing. Svoboda provides an important, relevant and innovative contribution to the scientific community at an acceptable level of depth and novelty for a PhD thesis. Innovative and creative contributions are found throughout the thesis, such as the innovative formulations and specific results of the decentralized LMI design steps.

Verdict

The author of the thesis proved to have the ability to perform research and to achieve scientific results. I do recommend the thesis for presentation with the aim of receiving a Ph.D. degree.

I kindly thank CVUT Praha and the CVUT Faculty of Electrical Engineering for the invitation to act as a reviewer of this thesis, and I wish Ing. Svoboda all the best in concluding his Ph.D. and in his further career!

Kind Regards,

Alexander Schirrer