Review of a Doctoral Thesis at FIT BUT

Doctoral thesis (hereinafter referred to as "thesis"):

Behavior Modeling for Tactical Pilot Training

by **Ing. Jiří HANÁK** (hereinafter referred to as "student")

Reviewer:

Prof. Dr.-Ing. Florian Holzapfel

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I. Thesis

Appropriateness and relevance

Is the area addressed by the thesis appropriate to the particular scientific discipline of the thesis and does the thesis address relevant problems within the chosen area?

The current situation in Europe and beyond undoubtedly proves that free and democratic societies must be prepared to defend their values and territories with armed forces. Currently, digitalization, autonomy, and other disruptive technologies have a significant impact on future warfare. In this transformation, it is essential that beyond state-of-the-art equipment, the soldiers are also trained realistically.

Piloted fighter aircraft constitute top-notch modern weaponry and put the highest demands on the humans operating them. Beyond physical aspects, this also includes intellectual capabilities. Beyond the technical operation of the system itself, situational awareness in complex tactical scenarios, a complete comprehension of the actual situation with all its threats and opportunities, and the capability to make fast and precise decisions in a rapidly evolving environment are some of the challenges to be met by the pilots.

Therefore, appropriate preparation in training cannot be limited to a proper high-fidelity representation of the physical aircraft system, and even the immersion by motion, sound, haptics, and high-quality visuals is not enough. It takes all participants' realistic and authentic behavior – friend and foe – in a complex tactical scenario. This also holds for computer-generated forces as it would neither be viable nor realistic to generate the behavior of all participants of a complex scenario by actual humans.

Univ.-Prof. doc. Ing. Peter Chudý, Ph.D., MBA, and his researchers are internationally renowned beyond other topics for their capabilities in flight simulation, including the capability to deliver high-fidelity, top-notch immersive simulation experience at unrivaled low cost.

Therefore, it is straightforward that Ing. Jiří HANÁK is supposed to utilize state-of-the-art methods in human behavior assessment, automation, machine learning, and artificial intelligence to implement reactive and collaborative agents representing realistic behavior of own and hostile participants.

The topic bears enormous potential due to the explanation above and the current global situation. Commencing the activities before the current conflicts escalated shows the far-sightedness of the Chudý group.

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A summary of the contributions of the thesis

From your point of view, please summarize what the goal of the thesis is, what the main contributions of the thesis are, and whether the thesis has achieved the chosen goal. Please indicate also specific contributions of the student.

To allow realistic tactical training of fighter pilots in complex scenarios without the need for humans to take the roles of simulated opponents and co-warriors, computer-generated forces appropriately need to adopt the tactical, flying, and decision behavior expected from human pilots on both sides.

The automation of the role otherwise played by human pilots shall be taken over by cognitive agents who are not supposed to act optimally but just like their human counterparts, including weaknesses like forgetting. Figure 3.16 on page 99 of the thesis perfectly visualizes all elements. Based on visual and aural perception, situational awareness is generated, forgetting behavior and context-dependent attention is added. Comprehension of the situation is achieved based on behavior trees. Polynomial chaos expansion is then used to project the outcome of different action alternatives based on the comprehended situation to allow a decision to be made, again based on behavior trees. The decision is then executed by a mission autopilot that leverages nonlinear model predictive control (NMPC).

The whole chain must be considered in a system of systems concept implementing a complex scenario. The approach must be scalable to many cognitive agents that can mutually communicate based on speech communication using brevity codes and datalink information. The scalability and the need for real-time operation drive the tactical framework architecture.

The perception behavior is based on human-in-the-loop experiments to match the behavior of professional and experienced pilots. Furthermore, it is essential that subject matter experts can transparently understand the trained behavior.

The whole approach of synthesizing the underlying cognitive processes was implemented, trained using experimental data, and evaluated. Thus, it may be concluded that the original goals set for the research have been successfully achieved.

The over-arching objective of the thesis is driven by user need, as currently, no ready-to-use solution is available to replicate human tactical behavior by cognitive agents in a scalable and explainable manner. Thus, both the architecture and the selection of appropriate methods for every step (listed above), their tailoring to the specific requirements, their implementation, training if needed, and evaluation can be considered the author's original contributions.

Novelty and significance:

Please assess the level of novelty of the results and their significance for the given scientific area, for its further development, and if applicable for possible applications in practice.

On the top level, the whole objective of providing a scalable architecture with cognitive agents exhibiting human-like behavior for large scenarios in air combat training by itself constitutes a remarkable novelty, as the state-of-the-art only provides somewhat rigidly mechanized automation of computer-generated forces based on scripted behavior. Human-like behavior and replicating flexible and dynamic decision capabilities are significant contributions.

This is a contribution of great significance as it promises to allow fighter pilots to train large scenarios realistically without the need for the involvement of many subject matter experts having to take the roles of the Red Force or the Blue Force wingmen.

However, also on the detail level, the work contains some impressive novelties beyond the state of the art of science and technology.

This comprises, for example, the perception model that trains a gaze model based on experimental evaluations with human pilots to realistically replicate the visual attention pattern. The concept of working memory appropriately models the time required to gain awareness of specific facts but also, more importantly, the human weakness of forgetting information again. Thus, in the work, decision-making is only driven by what is in the pilot's current awareness. Exponential functions are used to model the learning and forgetting behavior. Attention is modeled using discrete-time Markov Chains.

To select the best possible decision based on the current knowledge of the situation, many possible strategies must be explored to realize the projection mapping of the effect of actions taken under the current circumstances that the pilot is aware of and their possible outcome. Here, the explosion in computational demand is handled by approximating this relationship by surrogate models leveraging polynomial chaos expansion. Based on these projected outcomes and additional relevant information, the actual decisions are taken by a behavior tree.

While nonlinear model predictive control (NMPC) has been employed for a broad range of regular trajectory planning tasks, this thesis applies it to the maneuver pilot implementing the evasive or aggressive maneuvers commanded by the decision-making – another noteworthy novelty.

Evaluation of the formal aspects of the thesis:

Please evaluate formal qualities of thesis and its language level.

The submitted thesis is effectively structured into five well-defined chapters, each containing coherent content with seamless transitions. The language used is clear, understandable, and grammatically accurate.

The thesis also includes abstracts in English and Czech, acknowledgments, a list of figures, tables, acronyms, symbols, references, and appendices covering achievement and essential concepts integral to the thesis. All presented results are thoroughly explained, and the corresponding references are accurately cited.

An extensive array of drawings, schematics, and evaluation figures support the intuitive understanding and interpretation of concepts, methods, implementations, and results presented in the thesis.

The thesis fully meets the requirements expected of a dissertation work.

Quality of publications

Has the core of the thesis been published at an appropriate level? Please judge the quantity and quality of the publications. When judging the quality, please take into account internationally recognized standards (WoS/Scopus quartiles, CORE ranks, specific knowledge of flagship publication channels of a given community, etc.) in a way appropriate for the given area of the thesis.

As of today, Ing. Jiří Hanák has nine publications listed in Scopus, which is a firm number far beyond the number required to be eligible for a PhD defense at all the academic institutions I know.

These publications are well distributed over the prime dissemination outlets of the specific community. On the conference side that includes the ICAS as the global general-purpose Aerospace conference, the AIAA Aviation Forum as the most important, more tailored aerospace conference, and the IEEE/AIAA Digital Avionics Systems Conference as the highest-rated conference when it comes to also considering practical and application aspects of avionics.

Also, regarding journal publications, Mr. Hanák selected the AIAA Journal of Aerospace Information Systems, which I would also rate as the most relevant journal for avionics with an application flavor.

I am making a statement in favor of these selections here, as they perfectly match the publication selection strategy that my institute pursues in the domains covered by the thesis. To my knowledge, this is also well-reflected in the application-driven community.

Thus, from a publication perspective, Jiří Hanák exceeds the expectations to be put on a PhD candidate facing his thesis defense.

II. Student's overall achievements

Overall R&D activities evaluation:

Does the student's thesis, the results included into it, and possible other scientific achievements listed in the list of scientific activities indicate that he/she is a person with scientific erudition and creative abilities?

Ing. Jiří Hanák has been tasked with providing a functioning solution to a complex engineering challenge with high practical relevance for which no appropriate solution has been available.

Based on a thorough analysis of the nature of aerial combat and lessons learned, he decomposes the problem into all relevant aspects by himself (as already detailed above, not to be repeated here), abstracts them to identify possible solution strategies for every step based on state-of-the-art methods which then had to be extended by himself beyond the state of the art of science and technology to enable them to meet the requirements. Finally, he implemented each part of his concept in a well-structured and defined architecture to train, operate, and evaluate the whole system.

This does not only document his skills to develop original creative concepts and solutions beyond the state of the art at the scientific level on a broad range from modeling and simulation via machine learning to optimal control but also his engineering judgment, his comprehensive overview, and his capability to structure and decompose a broad challenge into suitable chunks. Also, conceptualizing an appropriate system architecture demonstrates the clarity of his understanding.

Finally, he demonstrated strong computational implementation skills.

So, in total, beyond impressively demonstrating the scientific erudition and creative abilities expected from a PhD candidate, he has also proven his engineering capabilities and skills, qualifying him as somebody who not only publishes papers but turns visions into reality to provide working solutions for demanding real-world challenges with an actual application demand.

Assessment of other characteristics:

More characteristics of the student may be added here (e.g., awards, grant participation, international collaboration, etc.).

For his publications on this thesis, Ing. Jiří Hanák has been awarded a Best of Session award at the IEEE/AIAA Digital Avionics Systems Conference (DASC) for two consecutive years (2023 and 2024).

Another item worth mentioning is that, following the philosophy of Univ.-Prof. Dr. Peter Chudý, also Mr. Hanák performed his research within application-driven projects with customers/contractors defining a real-world need. This significantly increases work effort and pressure on the candidate, requiring clearly defined deliverables and setting strict deadlines. This additional burden pays off by producing a real-life impact of the achieved results beyond scientific knowledge gain to be leveraged by simulator manufacturers and training providers to enhance the capability of our fighter pilots to safeguard and defend the skies of the free world.

III. Conclusion

*The conclusion should contain an explicit statement saying whether, in your opinion, the thesis and the student´s achievements until now meet the generally accepted requirements for the award of an academic degree (in accordance with Section 47 of Act No. 111/1998 Coll., on higher education institution).**

** Short overview of both the Act and corresponding internal BUT regulations is enclosed.*

The submitted thesis constitutes substantial research on a challenging and contemporary topic with significant potential for application. Utilizing a broad set of state-of-the-art methods, Ing. Jiří Hanák created a wide array of clearly definable original contributions beyond the current state of science and technology in tactical pilot training.

His work has been, on the one hand, implemented in a functional manner demonstrating real-life applicability and, on the other hand, disseminated to the scientific community in a significant number of Scopus-listed publications, with two of them being recognized with awards on one of the most acknowledged international conferences in the domain of digital avionics.

Thus, the candidate has impressively demonstrated his ability to carry out independent activities in his area of research and development, producing original and published results as mandated by Sec. 47 (4) of the Act. No. 111/1998 Coll.

Therefore, with emphasis, I recommend accepting his thesis and continuing the defense process, which will lead to awarding the aspired academic degree.

Garching, 19 January 2025

Prof. Dr.-Ing. Florian Holzapfel