Washkewicz College
of Engineering

ELECTRICAL ENGINEERING AND COMPUTER SCIENCE DEPARTMENT

August 9, 2023

Poznan University of Technology
Prof. Wojciech Szelag, PhD, D.Sc
Chair of the Discipline Council of Automation, Electronics,
Electrical Engineering and Space Technologies
ul. Piotrowo 3A, 60-965 Poznan
Poland

Dear Prof. Wojciech Szelag,

It is my pleasure to review the dissertation of Radosław Patelski, titled "The Problem of the Modeling Uncertainties in the Paradigm of the Active Disturbance Rejection Control." It is my belief that this dissertation successfully meets both criteria in *Article 187 section 1* and I recommend without any reservation for its public defense, leading to possible award of the Ph.D. degree to Mr. Patelski.

My detailed review is attached here for the considerations of the dissertation committee. It's sent both by email and the regular USPO mail.

Please feel free to contact me regarding this review.

Sincerely yours,

Zhiqiang Gao, Ph.D.
Associate Professor and Director
Center for Advanced Control Technologies
216-687-3528, z.gao@csuohio.edu

Subject of the review: Dissertation: "The Problem of the Modeling Uncertainties in the Paradigm of the Active Disturbance Rejection Control." By Radosław Patelski,

Reviewer: Zhiqiang Gao, Cleveland State University, August 9, 2023

Criteria: *Article 187 section 1*

1. The doctoral dissertation presents general theoretical knowledge of the Candidate in the discipline as well as his ability to independently conduct scientific or artistic work.

2. The subject of the doctoral dissertation shall be an original solution to a scientific problem, an original solution to the use of the results of own scientific research in the economic or social sphere or an original artistic achievement.

Assessments

I. ***Criteria 1***: *"general theoretical knowledge of the Candidate in the discipline as well as his ability to independently conduct scientific or artistic work"*

With 351 references, the candidate provided an excellent panoramic view of the entire field of robust control and disturbance estimation, accommodation and rejection, with acute understanding of each individual work and the ability to piece together a wholistic view. The presentation is concise and clear throughout, making it an easy read for the reviewer. In particular, the history of each branch of studied is provided, leading to much insight and a rich context, which led to the foundation and motivation for the work in this dissertation.

Given that the research in this dissertation has been conducted within the paradigm of ADRC, and given that this paradigm was initially put forward in 2001 CDC and articulated fully in 2006 ACC, primarily by this reviewer, the following comments/suggestions are offered the foundational concepts, such as disturbance and model, that take on new meanings beyond the convention.

Comment 1: ADRC as a new paradigm: redefine the concept of disturbance

In this dissertation, the recount of history in the evolution of ADRC was particularly unique, where the previously largely neglected work, from Feng [69], Hou [110], to Han [101], were reconnected to the whole. The crucial difference, however, is that ADRC was elevated to the level of paradigm, as opposed to merely a technique or method under the paradigm of model-based control theory, for the first time in 2001 [84] (note the word Paradigm in the paper's title). This distinction may impact the narrative in this dissertation in the following way.

ADRC was lumped under DOB earlier in the dissertation, see Figure 1.3. However, the concept of disturbance in ADRC is quite different from that in DOB, and this may become a source of confusion. From the early work of C.D. Johnson and of the original DOB of 80s, to the present day literature, "D" stands for disturbances independent of plant dynamics or states. The disturbance rejection or accommodation back then was done strictly under the assumption that the plant model is given and accurate. This is a premise ubiquitous in the paradigm of classical and modern control theory, deeply embedded in both the mindsets and textbooks of our university curriculum.

ADRC rose rapidly in recent years as an alternative to the model-based paradigm. But the D in ADRC is often mistaken for the D in DOB, leading to some unfortunate misunderstanding in the West, such as

ADRC is a subset of disturbance rejection in the conventional sense. In the Chinese literature, however, the situation is better because of the seminal paper by Han in 1989 that directly challenged the model-based control theory. The title of the paper has been heard, but no necessarily agreed upon, by all in the Chinese control community: "Control Theory: A Theory of Model or a Theory of Control."

The candidate may want to add a comment to clarify this distinction around Figure 1.3 on page 10.

In the literature of ADRC, the challenge has been to make it clear once for all that the D in ADRC stands for "total disturbance", which include both internal and external ones. The former refers to the ones that are state dependent and was denoted as unmodeled dynamics. This denotation would also have profound impact on the concept of "model" in control theory, as explained below.

Comment 2: ADRC as a new paradigm: redefine the concept of (nominal) model

The candidate describes ESO as an "algorithm to online estimate a difference between the controlled plant and its assumed nominal model". Here the term "assumed nominal model" refers to the cascade integrators form, or simply an integrator chain. Han himself argued in the paper from 1979 (Chinese) that both linear and nonlinear plants can be reduced to such an integrator chain, on which controller is to be designed. This is the bedrock in his work throughout the years, before and after ADRC. And this constitutes the core principle in his development of ESO in 1995 and ADRC in 1998, with both papers written in Chinese and were never translated. So instead of the common term of "nominal model", which usually means the mathematical description of the physical plant, this "assumed nominal model" refers here is simply an integrator chain in the context of ADRC.

Together with the redefined concept of disturbance, as discussed above, this concept of model as something not necessarily resembles the actual plant but, instead, is something forced upon it, is arguably the defining characteristics of ADRC in the new paradigm. The importance of making this clear in conjunction with the field of conventional disturbance rejection and accommodation can be hardly underestimated.

In other words, the crucial concepts such as disturbance and model are given brand-new, eye-opening, interpretations in the context of ADRC. And we need to be extra careful in avoiding confusions when we discuss them in conjunction with the existing field of control theory and applications.

The implication of such conceptual innovation in the paradigm of ADRC is profound. In the same paper from 1989, Han pointed out that the complexity in system dynamics makes modeling in robotics an effort often ends in "disasters". Looking back, what he meant is that, with ESO, what plant dynamics needs to be modeled is an important question in control theory, one that has been asked before. A short, oversimplified answer is that what can be easily estimated by ESO doesn't need to be modeled.

Comment 3: Difference in methodology: The methods of the first stability analysis of ADRC: the main result in [347] was not Lyapunov-based.

The Lyapunov methods have been tool of choice for generations of control researchers, often deemed as the gold standard by the majority. But the main results in [347] by Q. Zheng et al was not Lyapunov based, even though the Lyapunov method was used there for the unlikely cases of h is completely known. For most cases ADRC was designed to solve, where h is unknown, the paper used a refreshingly simple method based on the solution of the linear differential equation. This was new and it paved the way to overcome early difficulties in analysis of ADRC and attracted many researchers to the fields with more powerful weapons.

As pointed out later in the dissertation, conservativeness in the existing paradigm in terms of control design and stability analysis is one roadblock responsible for the gap between theory and practice. ADRC developments, as candidate shows in Figure 2.1 on page 20, was driven by applied research and experimentations, free of stability constraints in the early stages I would add. Once the success of ADRC in the field was accepted as norm, rather than exception, theoretical analysis naturally followed, in both frequency and time domain.

To me, what is the best methods to build the theoretical support for ADRC is still an open question.

II. ***Criteria 2**: The subject of the doctoral dissertation shall be an original solution to a scientific problem, an original solution to the use of the results of own scientific research in the economic or social sphere or an original artistic achievement.*

The candidate formulated the scientific problem to be studied on the robustness of ADRC, recognizing the current limitations and set the ground for his own research. And this was done very well.

The candidate was able to show robustness of ADRC based on both the current literature and the experiments of his own, in Chapter 2. The nature of ADRC paradigm was captured brilliantly on top of page 19. I wish this was done earlier to help readers get the clear idea from the beginning that this research was performed in a different paradigm, and the rationale behind it.

In particular, the inclusion of input path dynamics was original and important in connecting theoretical study with practice. In the early days of control development in the middle of last century, the term "final control element" was used to, I believe, represent the element of control system between the controller and the process to be controlled. It is really refreshing to see the candidate was able to include it in the study and making it central in the dissertation research.

Finally in Chapter 3, the candidate proposed the solution to the robustness problem of ADRC, by combining adaptive control with ADRC. The history of Adaptive Control was first given. Here I'd like to point out that the original motivation for adaptive control and ADRC were quite similar, in addressing uncertainties in plant dynamics. However, one evolved within the model-based control paradigm, the other outside it. By nature, ADRC has solved much of the uncertainty problems Adaptive Control was concerned with originally. The combination of Adaptive Control and ADRC is therefore a high level one, i.e. incorporating parameter adaptation into ADRC to further expand its robustness. The readers may appreciate such insight and gain a better understanding of what the candidate has done in this dissertation.

The method proposed by the candidate is novel, supported by both theoretical rigor and practical validation. Well done!

III. Some general comments and suggestions

1. The candidate did a great job integrating various problems, analysis and solutions in the area of ADRC into a whole and then put the principles to work in two case studies. It's by no fault of the candidate that state of the art stability analysis, as summarized and integrated in section 2.2, has yet to show effectiveness in guiding the engineering practice in various vast domains of ADRC practice. Perhaps there are other and better ways to rationalize the practice of ADRC in all its diversities, not limited to methods such as the analytical methods of modern control theory.

   For example, the problem of input gain uncertainty can't be separated from the problem of control in the first place. In most cases pertaining to industry practice, a physical process is designed and manufactured to perform certain tasks or to possess certain dynamic characteristics.

Central to its design is the causal relationship between the input and output, which must be carefully constructed. So engineers do not come into control practice blind and the input uncertainty should be characterized accordingly in mathematically terms but with full insight of engineering practice.

2. Before ADRC is discussed in any length, one should first make clear in what context ADRC is interpreted: is it as a paradigm, as design principles, or as algorithms to particular problems? Han was adamant in explaining that his articulation of ADRC design for a typical second order plant is but an illustration of the principle he tries to demonstrate. A common mistake in literature is to take Han's example as ADRC itself and blindly copy-paste to other problems. The analysis and examples in this dissertation goes a long way to address the misunderstandings, but much work is still ahead.

3. Adaptive ADRC proposed here is paving the way for incorporating higher level intelligence, such as machine learning, into lower-level control loops, because learning in its essence is adaptive. I believe that the candidate, having finished the work in this dissertation, is well prepared to take the next step. One advice I'd like to offer is that don't tie your hands with stability analysis at the front end. Take the cue from the history of ADRC: as good as a mathematician Han was, he invented ADRC in his 60s and, in his own words, let others worry about the stability proof. Proving stability others did, but only after evidence of success in the field of engineering became overwhelming.

In **conclusion**, this reviewer believes that the dissertation by Radosław Patelski successfully meets both criteria in Article 187 section 1 as stated above and I recommend without any reservation for its public defense, leading to possible award of the Ph.D. degree to Mr. Patelski.