ONS KENMERK To Prof. **Ing**. Zbyněk Škvor
UW KENMERK Vice-Dean for Science and Research
LEUVEN Czech Technical University in Prague

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Review by Lieve Helsen, KU Leuven (Belgium)

To what extent the subject of the thesis is relevant to current needs of the scientific community
Today a lot of effort is put in research concerning the development of model based predictive control (MPC) of e.g. heating/ventilation/air-conditioning (HVAC) systems in buildings. The bottleneck in MPC development for HVAC systems in buildings is the development of a simple but accurate dynamic system model to be used in the controller, in other words how can we derive an appropriate controller model from time series data measured in the building? Or even stronger: which controller model should be used when there are even no measurement data available? The work of Zdenek Vana is focused on the development of a new approach for system identification using Discrete Wavelet Transform (DWT), thus contributing to the development of methodologies to derive appropriate system models for predictive control based on measurement data. The approach is generic in nature and thus not restricted to one particular application, which is a strong point.

Conclusion: this work can be classified as very relevant to current needs of the scientific community.

To what extent the main objectives of the work have been fulfilled
The main objectives of the work are defined as:

- To perform a comprehensive survey of methods exploiting the wavelet transform for system identification.
- To find and describe a suitable way of incorporation of wavelet transform into a general single-input single-output (SISO) linear system identification problem, analyse the method and demonstrate it on a suitable example.
- To extend the method to multivariable systems, analyse the method and demonstrate it on a suitable example.
- To investigate and find the use of wavelet transform within continuous-time linear system identification, including a discussion on implementation issues.

The candidate has fulfilled all these objectives, and even more, some of the related work is published in peer reviewed papers (as clearly listed on p.89-93 of the text), which means that the work has been reviewed and approved by international experts within the field. The published work scores high in both quality and quantity (8 journal papers of which 2 as first author, and 15 international conference papers of which 3 as first author), not all papers being directly related to the PhD thesis. The candidate has been able to convert the teamwork into synergy, using applications from other PhD studies to illustrate the newly developed approach, and to compare with other methods. By interconnecting two theories (wavelet transform and system identification) different scientific fields are crossed, which shows a creative way of thinking out-of-the-box. This characterizes researchers that make a difference.

Conclusion: the main objectives have been fulfilled.

To what extent the methods used in the thesis have been appropriate
The methods used in the PhD thesis originate from system identification and data analysis, crossing the border of different scientific fields, leading to a new approach that is general in nature and can as such be applied to different engineering applications. The clear focus (a general concept for single and multivariable system identification by wavelet transform to generate a linear model suitable for control, both for continuous-time and discrete-time) and stepwise approach (starting from a survey, SISO, asymptotic properties, MISO, MIMO, continuous-time), where in each step the performance is

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demonstrated by a case (simulation or real-life), makes the methodology followed very strong and convincing. The origin of wavelet analysis is nicely introduced and the principles are clearly described and applied, illustrating the strengths and limitations of the method. System identification by wavelet transform is a natural way of selecting important information hidden in data series and therefore convenient for identification of the dominant modes of the system such that a particular frequency range of interest can be selected. The signal is analyzed from both time and frequency points of view: analysis in time proceeds by shifting the wavelet along the time axis, and analysis in frequency proceeds by scaling the wavelet.
Remark: cases are described in a very concise way. I have doubts about the correctness of Equations (7.2): I would expect overall heat exchange coefficients (instead of $c_w m$) in the terms containing the temperature differences ($T_{SW} - T_C$) or ($T_{RW} - T_C$).

Conclusion: The methods used are appropriate.

What are the main results and contributions of the work?
The main result is the development of a new approach to use wavelet transform in the field of system identification. The number of applications found in the literature was limited, and the ones available did not consider general wavelet functions. The new approach brings several advantages:

- The set of wavelet functions forms a set of filters
- No information carried in the signal is lost since all convolutions are exactly computable
- Each filter extracts the specific portion of information from the signals without any duplicity, which contributes to numerical conditioning of the algorithm
- Theory of wavelet frames covers the wavelet functions that do not satisfy the necessary condition given by the wavelet theory.
- The method is quite generic and intuitive, only weights need to be tuned (which requires some knowledge of the system). The implementation itself requires deeper understanding of wavelet theory.

The thesis gives a good description of wavelets, enabling the reader to understand both the wavelets and mutual consequences between wavelets and system identification. The interconnection between both theories is a very important contribution of this PhD. The new approach can be applied in different fields, which is another strong point.

Conclusion: The PhD has generated very valuable results and contributions to more than one field.

To what extent is the work important for the further development of science
This work is very important for further development in science. The new approach allows extracting appropriate information from series of measurement data by wavelet transform. As such the signal is analyzed from both time and frequency point of view and results in good performance of system identification for controller models. Measurement data are more and more available, however appropriate data analysis and translation of the information contained in the data series into a controller model that captures the relevant dynamics is a challenge. In this PhD a general approach is presented and illustrated. The next challenge is to derive an initial controller model for a new building for which no measurement data are available.
One question remains: the approach has been developed for linear models. What if it is applied to non-linear systems?

Conclusion: The work is very important for the further development of science.

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Whether the thesis satisfies conditions of a creative scientific work

The PhD candidate succeeded in connecting two scientific fields: wavelet transform and system identification. This connection leads to a new and general approach for system identification, which is not restricted to one specific application. Different cases have been used to illustrate the approach. The candidate has performed this work in a solid way, leading to innovative and creative work. The combination of thorough theoretical work and application to cases is an additional strength of this research work.

My conclusion:

The author of the thesis proved to have an ability to perform research and to achieve scientific results. I do recommend the thesis for presentation with the aim of receiving the Degree of PhD.