30. 11. 2015

Ph.D. Thesis Review

Reviewer: Prof. Ing. Pavel Zítek, DrSc.
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Author: **Ing. Milan Anderle**
Title:

Modelling and Control of Walking Robots

Characterisation and significance of the topic

The Thesis deals with novel techniques in modelling and control of the so-called under-actuated walking robot motion where actuator number is less than the degree of freedom of the mechanical system. The walking mechanism as such is nonlinear system and an exact feedback linearization is applied to the control system synthesis. The theoretical investigations of the walking control are closely connected with the well-known Acrobot scheme being developed a couple of years ago. The author is a member of the research team of professor S. Čelikovský and all the authors' publications referenced in the Thesis are authored with the team colleagues and the team head. Nevertheless it is to emphasize that the author's publication list is remarkable: In **one paper** in impact-factor Journal of Control and in **three further** publications indexed in Web of Science Ing. Milan Anderle is the first author. Although the thesis is conceived self-consistent the presented text is written with close reference to the above mentioned publications. It is only a pity that no attempts of experimental verifying of the control algorithms are mentioned in the Thesis. As far as I remember – certain experimental attempts have already been performed in the team.

Applied theory and contribution

In elaborating the Thesis the author often refers to the articles where he is one of the authors. These papers are prestigious but the thesis is conceived as self-consistent work of a single author. Just with respect to this occasion the author should pay more special attention in order to distinguish **his own contribution** to the final solution from the earlier results in the research of the walking control problems in the team. As to my knowledge I suppose that the contribution should not consist in Chapter 2 and also the method of exact feedback linearization in Chapter 3 was already markedly worked out before this Thesis. On the other hand, in comparison with the previous works the design of two reference trajectories for Acrobot and for four-link mechanism and their critical comparison developed in Chapter 4 apparently contain new results in the walking control modelling. Proving the multi-step design of the reference walking trajectory as more advantageous than the pseudo-passive approach I suppose to be one of the main contributions. A similar conclusion I suppose in Chapter 5 where an analytical synthesis of the so-called exponential tracking is proposed. Further original contributions probably are in the observer application in Chapter 6 and in the stability analysis of the walking motion in Chapter 7.

Comments and suggestions.

The objectives of the thesis set on page xi are of a challenging extent, but I am not convinced that all of this extent represents only new contributions. Detailed comments:
P. 11 and 16 – Originally the potential energy symbol is P, from p.16 it is changed to V without an explanation. Although friction is a prerequisite of the gait as such the motion equations are considered as friction free in this part.
P. 15 – The author uses a strange term "material parameter equations" instead of moment of inertia equations.

P. 16 – Very strange is the end of Subsection 2.1.2, p. 16: "Nevertheless, for brevity neither the form of (Euler-Lagrangian equations) nor final model matrices are given here in detail." Although this section of the Thesis does not represent the author's contribution the final form of the considered model is to be presented.
P. 17 – The assumptions concerning the impact model: It is clear that the rebound and slipping is excluded but it is hard for me to accept the assumption of the impulse character of reaction forces. After touching the ground the stance leg is in contact for a time necessary to moving the centre of gravity of the torso. During this time interval the reaction force lasts and the actuators are exposed to this force and that is why I would not expect an instantaneous impulse character of this load. The force is stepwise variable in time – but not as instantaneous impulses – and the actuator is loaded accordingly in this manner.
P. 29 – "corresponds to the undeactuated angle q_1 ..." under-actuated is the mechanism, not the angle.
P. 36, 49 – Figures 4.2 and 4.10 are without any description. What actually is depicted in these graphs?
P. 37 – The virtual constraint functions $\Phi_{3,4}$ are presented without an acceptable explanation. What is to be constrained and what does mean the equalities (4.3)?
P. 39 – Equation (4.4) is unclear, it should be a "matrix" but $q'(0)$ is a vector.
P. 49 – Fig. 4.9: The walking is to be expected as rather periodic motion, but the presented graphs do not show marks of this nature. Why?
P. 50, 51 – Figures and their commentary. The graphs allegedly depict the same variables with very different patterns, even with a case of "simulation crash". Such controversial results deserve much more explanation and discussion than the seven-row conclusion on P. 52.

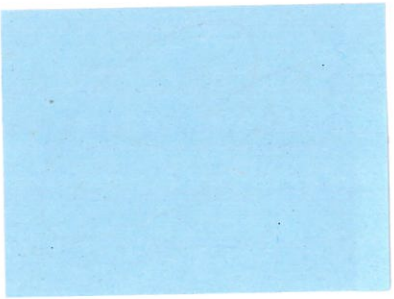
Questions to discuss

1. The author should specify more precisely his personal contribution to the presented research results.
2. What indeed is the motivation for impulse interpretation of the touching the legs to the ground?
3. Please, give a deeper explanation to the results in Sections 4.2.1 and 4.2.2

Contribution and conclusion.

It is beyond a doubt that the Thesis by Ing. Anderle brings a novel contribution to designing the control algorithms for under-actuated walking robots. Although the author should more precisely specify which of the new ideas and results belong to his own authorship the group of 13 publications where he is the first author is a relevant evidence of his personal contribution. Although the main approaches as the exact feedback linearization, the reference trajectory tracking algorithms were already known the author has brought new innovations and refinements particularly in the multi-step design in the reference trajectory tracking, in the reduced-order observer application and in the stability analysis of the walking motion. The above critical comments are not to cast doubt upon the original contribution of the present work. The thesis by Ing. M. Anderle has fulfilled the criteria of the §47 of the University Education Act No. 111/98 of the Czech Rep. and **I recommend it to the Ph.D. defence.**

November 29, 2015



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