SCYR

Scientific
Conference
of Young
Researchers
2019

19th Scientific Conference of Young Researchers

April 12, 2019
Košice, Slovakia

Proceedings from Conference

Faculty of Electrical Engineering and Informatics
Technical University of Košice

Co-Organizers

Sponsors

19th Scientific Conference of Young Researchers
of the Faculty of Electrical Engineering and Informatics
Technical University of Košice

Proceedings from Conference

Published: Faculty of Electrical Engineering and Informatics
Technical University of Košice
Edition I, 190 pages, number of CD Proceedings: 50 pieces

Editors: prof. Ing. Alena Pietriková, CSc.
Ing. Peter Gnip
Ing. Tomáš Tarkanič
Ing. Emília Pietriková, PhD.

ISBN 978-80-553-3273-4

Program Committee of 19th Scientific Conference of Young Researchers of the Faculty of Electrical Engineering and Informatics, Technical University of Košice

General chair: Prof. Ing. Liberios Vokorokos, PhD.

Editorial board chairman: Prof. Ing. Alena Pietriková, CSc.

Proceeding reviewers:
Prof. Ing. Roman Cimbala, PhD.
Prof. Ing. Ján Paralič, PhD.
Prof. Ing. Daniela Perduková, PhD.
Prof. Ing. Alena Pietriková, CSc.
assoc. Prof. Ing. František Babič, PhD.
assoc. Prof. Ing. Ján Gamec, CSc.
assoc. Prof. Ing. Ján Genči, PhD.
assoc. Prof. Ing. Kristína Machová, PhD.
assoc. Prof. Ing. Ján Papaj, PhD.
assoc. Prof. Ing. Jaroslav Porubän, PhD.

Organization Committee of 19th Scientific Conference of Young Researchers of the Faculty of Electrical Engineering and Informatics, Technical University of Košice

Members:
Prof. Ing. Alena Pietriková, CSc.
Ing. Ivana Olšiaková
Ing. Peter Čech
Ing. Dominika Čupková
Ing. Branislav Fecko
Ing. Peter Gnip
Ing. Michal Ivančák
Ing. Viera Maslej Krešňáková
Ing. Michal Márton
Ing. Dominik Nezník
Ing. Emília Pietriková, PhD.
Ing. Alojz Šoltýs
Ing. Tomáš Tarkanič

Contact address:
Faculty of Electrical Engineering and Informatics
Technical University of Košice
Letná 9
042 00 Košice
Slovak Republic

Contribution to Modeling and Control for Walking Robots Using Hybrid Systems

[1]*Lukáš KOSKA (2*nd *year),*
Supervisor: [2]*Anna JADLOVSKÁ*

[1,2]Dept. of Cybernetics and Artificial Intelligence, FEI TU of Košice, Slovak Republic

[1]lukas.koska@tuke.sk, [2]anna.jadlovska@tuke.sk

***Abstract*—This paper presents a research work and the results, which were gained over the last year in the field of modeling and controlling hybrid walking systems. Various model configurations have been designed as a part of the modeling, based on the simplest compass gait model. In the field of controlling, the generation and the tracking of trajectories was verified for a benchmark underactuated system. The theory of hybrid systems was used to solve research tasks within the experiment ALICE in the CERN.**

***Keywords*—hybrid systems, walking models, trajectory generation, detector-control system**

I. INTRODUCTION

Biped locomotion is one of the most sophisticated forms of the movement. In terms of dynamic systems, human walking stands out above the other forms of biped locomotion due to the fact that during a major part of the step, the moving body does not occur in the static equilibrium position [1].

One of the most important reasons for studying the human locomotion is its effectiveness. For example, in difficult terrain, in comparison to the wheel machines, it is easier for two or more leg robots to walk, thanks to its versatility [2]. The movement of the robot's legs while passive walking on the inclined plane is controlled by its own dynamics powered by the gravitational acceleration g [3]. The aim of the control of underactuated walking is to utilize the natural dynamics of the robot, because the control is more efficient and adds less power to the system than the control which exactly tracks the reference trajectory of the fully-actuated system [4].

II. PREVIOUS ANALYSIS AND ACHIEVED RESULTS

While modeling of walking as such, it is necessary to consider not only the continuous dynamics of the legs but also the discreet events that occur when swing leg impacts the ground. For this reason, it is the most useful to use the concept of the hybrid systems that combine the continuous and discrete dynamics of the model [5]. Hybrid systems, along with the state automaton theory, also provide framework for modeling and controlling of the hybrid systems of the research project *Experiment ALICE on LHC in CERN: Study of strongly interacting matter at extreme energy densities* [6].

In a modeling of walking, each discrete state x_d is described by its own continuous dynamics f_{x_d}. In the case of mechanical systems, such as underactuated walking robots, this leads to using of the Lagrange equations for deriving of non-linear differential motion equations of the walking system.

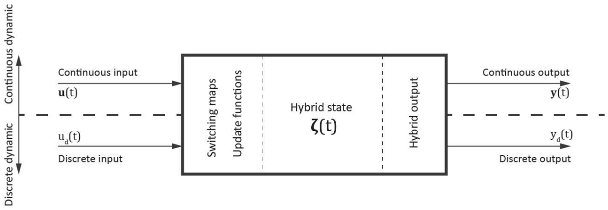

Figure 1. Description of the hybrid biped locomotion

The discrete dynamics, which is one part of the overall dynamics of the hybrid system, it is defined by the existence of events specified by the extended hybrid state vector $\boldsymbol{\zeta}(t) = (\boldsymbol{x}(t), \boldsymbol{u}(t), x_d(t), u_d(t))$, where $\boldsymbol{x}(t)$ represents a continuous state-space vector, $u(t)$ is a continuous input, $x_d(t)$ discrete state vector and $u_d(t)$ discrete input. When modeling of the discrete dynamics, which is defined by occurrence of the discrete events in the walking systems, is used the fact that each planar robot can be simplified into a kinematic chain [7].

Collisions in this kinematic chain are modeled as discrete events, because it is assumed that as a result of collision, an immediate change of speeds $\dot{\boldsymbol{\theta}}(t)$ will appear. If the impact force F_i does not generate the momentum when the swing leg impact the ground, the momentum of it is retained at this point. Exactly this fact is used to create and derive a discrete model of walking systems [8].

Since walking systems must exhibit periodic behavior when walking, for their analysis, limit cycle and Poincaré maps are used. Poincaré maps simplify the analysis of the limit cycle for analyzing one fixed point [9].

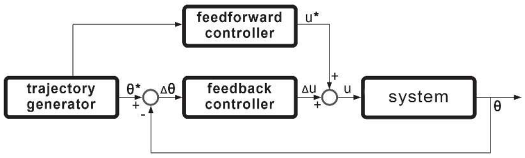

Figure 2. Feedforward control structure

Several control methods have been developed to control the biped locomotion, most of them use a feedforward control structure [8], which is shown in Fig. 2.

A crucial feature of the planned motion of an underactuated robotic walk is periodicity, which is the difference in comparison to the trajectory planning for simple benchmark underactuated systems such as cart and pole system, serve to

Figure 3. Model of the Compass Gait

verify control methods for the robotic walking [10].

III. SOLVED TASKS

Model of the Compass Gait - (CG), shown in Fig. 3 represents the basic and the passive walking model, which was first studied in the work of the research group Goswami et. al. [11].

The dynamics of the swing and stance legs can be derived when using Lagrange equations. The discrete dynamics of the CG model includes only one situation when the swing leg falls on the ground. If the collision condition $s(\boldsymbol{\theta}) : \theta_{NS}(t) + \theta_S(t) + 2\alpha = 0$ is fulfilled, the swing leg becomes stance and stance leg becomes swing leg.

The robotic walking model creates a closed limit cycle. Fig. 4 shows that using the nonlinear differential equations for the continuous dynamics and the equation for discrete dynamics, it allows to obtain a closed limit cycle when appropriate initial conditions.

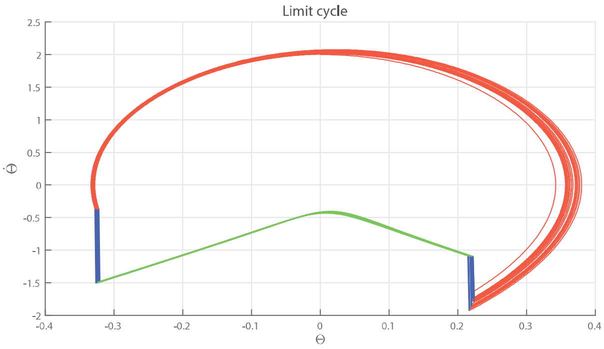

Figure 4. Simplified phase portrait of the Compass Gait model

Since the underactuated walking robots are the part of the more complicated systems, it is preferable to verify the motion planning methods firstly on a suitable benchmark underactuated systems such as, cart and pole [12] [13].

When using the two-point boundary problem, it is neccesary to modify the model of the cart and pole system. The modification consists of replacement the cart with the linear aproximation of the LSM. After the modification, it is possible to use the solution of the two-point boundary problem for the design of the trajectories from the lower stable to the upper unstable equilibrium position of the pendulum, which is dealt with in the article called *Inverted pendulum with linear synchronous engine swinging using boundary value problem* (Koska et.al.) which was sent to a foreign journal. A significant part of the results are shown in Fig. 5.

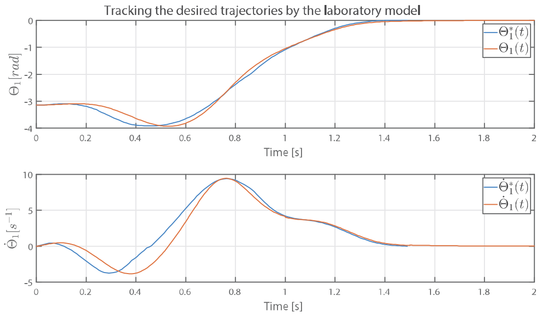

Figure 5. Tracking of the desired pendulum angle $\theta_1^*(t)$ and the angular velocity $\dot{\theta}_1^*(t)$ against the laboratory system pendulum angle $\theta_1(t)$ and angular velocity $\dot{\theta}_1(t)$

IV. FUTURE RESEARCH STEPS AND CONCLUSION

This article summarizes the author's research activity over the last year. The aim in the next thesis is to design the methodology of generating mathematical models of hybrid walking systems with different configurations, and also to adequately design control methods for different model configurations.

Further research activities of the author will be focused on the design of the intermediate level communication of the *Detector Control System* for ITS subdetector within experiment ALICE in the CERN using a model workplace within the KKUI FEI TU.

ACKNOWLEDGMENT

This work has been supported by grant KEGA Implementation of research results in the area of modeling and simulation of cyber-physical systems into the teaching process - development of modern university textbooks – 072TUKE-4/2018 (100%).

REFERENCES

[1] A. Goswami, B. Thuilot, and B. Espiau, "Compass-like biped robot part i: Stability and bifurcation of passive gaits," Ph.D. dissertation, INRIA, 1996.

[2] H. Chen *et al.*, "Passive dynamic walking with knees: A point foot model," Ph.D. dissertation, Massachusetts Institute of Technology, 2007.

[3] L. Koska, "A survey of approaches for modeling and control of effective walking robots," in *SCYR 2018*. TU, 2018, pp. 16–19.

[4] Y. Liu and H. Yu, "A survey of underactuated mechanical systems," vol. 7, no. 7, p. 921–935, 2013.

[5] T. McGeer *et al.*, "Passive dynamic walking," *I. J. Robotic Res.*, vol. 9, no. 2, pp. 62–82, 1990.

[6] P. Chochula, L. Jirden, A. Augustinus, G. De Cataldo, C. Torcato, P. Rosinsky, L. Wallet, M. Boccioli, and L. Cardoso, "The alice detector control system," *IEEE Transactions on Nuclear Science*, vol. 57, no. 2, pp. 472–478, 2010.

[7] M. Sobotka, "Hybrid dynamical system methods for legged robot locomotion with variable ground contact," Ph.D. dissertation, Technische Universität München, 2007.

[8] S. Gupta and A. Kumar, "A brief review of dynamics and control of underactuated biped robots," *Advanced Robotics*, vol. 31, no. 12, pp. 607–623, 2017.

[9] I. A. Hiskens, "Stability of hybrid system limit cycles: Application to the compass gait biped robot," in *IEEE conference on decision and control*, vol. 1. IEEE; 1998, 2001, pp. 774–779.

[10] L. Tedrake, Russel, *Underactuated Robotics: Learning, Planning, and Control for Efficient and Agile Machines*, 2009.

[11] A. Goswami, B. Espiau, and A. Keramane, "Limit cycles in a passive compass gait biped and passivity-mimicking control laws," *Autonomous Robots*, vol. 4, no. 3, pp. 273–286, 1997.

[12] A. Jadlovská, S. Jadlovská, and D. Voščcek, "Cyber-physical system implementation into the distributed control system," *IFAC-PapersOnLine*, vol. 49, no. 25, pp. 31–36, 2016.

[13] E. R. Westervelt, J. W. Grizzle, C. Chevallereau, J. H. Choi, and B. Morris, *Feedback control of dynamic bipedal robot locomotion*. CRC press, 2007, vol. 28.