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Bram Vanderborght

Dynamic Stabilisation of the Biped Lucy Powered by Actuators with Controllable Stiffness

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Foreword

Robotics is undergoing a major transformation in scope and dimension. From a largely dominant industrial focus, robotics is rapidly expanding into human environments and vigorously engaged in its new challenges. Interacting with, assisting, serving, and exploring with humans, the emerging robots will increasingly touch people and their lives.

Beyond its impact on physical robots, the body of knowledge robotics has produced is revealing a much wider range of applications reaching across diverse research areas and scientific disciplines, such as: biomechanics, haptics, neurosciences, virtual simulation, animation, surgery, and sensor networks among others. In return, the challenges of the new emerging areas are proving an abundant source of stimulation and insights for the field of robotics. It is indeed at the intersection of disciplines that the most striking advances happen.

The *Springer Tracts in Advanced Robotics (STAR)* is devoted to bringing to the research community the latest advances in the robotics field on the basis of their significance and quality. Through a wide and timely dissemination of critical research developments in robotics, our objective with this series is to promote more exchanges and collaborations among the researchers in the community and contribute to further advancements in this rapidly growing field.

The monograph written by Bram Vanderborght is the third in the series devoted to biped robots. The work speculates on the study of human walking to ensure a suitable compliant behaviour for a pneumatically actuated biped. A complete hardware and software architecture is developed and different planning and control techniques are tested for energy efficient walking.

The monograph is expanded from the doctoral dissertation of the author, which was a finalist for the Eight Edition of the EURON Georges Giralt PhD Award. A very fine addition to STAR!

Naples, Italy
January 2010

Bruno Siciliano
STAR Editor

Preface

This book reports on the developments of the bipedal walking robot Lucy. Special about it is that the biped is not actuated with the classical electrical drives but with pleated pneumatic artificial muscles. In an antagonistic setup of such muscles both the torque and the compliance are controllable. From human walking there is evidence that joint compliance plays an important role in energy efficient walking and running. Moreover pneumatic artificial muscles have a high power to weight ratio and can be coupled directly without complex gearing mechanism, which can be beneficial towards legged mechanisms. Additionally, they have the capability of absorbing impact shocks and store and release motion energy. This book gives a complete description of Lucy: the hardware, the electronics and the software. A hybrid simulation program, combining the robot dynamics and muscle/valve thermodynamics, has been written to evaluate control strategies before implementing them in the real biped.

The current control architecture consists of a trajectory generator and a joint trajectory tracking controller. Two different trajectory generators have been explored. The first is based on an inverted pendulum model where the objective locomotion parameters can be changed from step to step. The second is an implementation of the preview control of the zero moment point developed by Kajita. The joint trajectory tracking unit controls the pressure inside the muscles so the desired motion is followed. It is based on a computed torque model and takes the torque-angle relation of the antagonistic muscle setup into account. With this strategy the robot is able to walk up to a speed of $0.15m/s$. Higher walking speeds are difficult because the robot has to walk flat-feet and the valve system is not fast enough to follow the predescribed pressure courses.

On a single pendulum structure a strategy is developed to combine active trajectory control with the exploitation of the natural dynamics to reduce energy consumption. A mathematical formulation was found to find an optimal compliance setting depending on the trajectory and physical properties of the system. This strategy was not implemented on the real robot because the walking speed of the robot is currently too slow.

Acknowledgements

First of all, I would like to thank my promotor Dirk Lefeber to let me walk freely where I found the road ahead myself, but also for assisting me when needed.

Robotics is a very multidisciplinary research domain, which demands for the most varying competencies. It is thus immensely important to work within a team of enthusiastic people. This was for me one of the key factors for deciding to do my masters thesis and afterwards my doctoral thesis in the Robotics & Multibody Mechanics Research Group. Although a dissertation has only one author, the work was only possible by a close collaboration with the group members. I'm especially grateful to Björn Verrelst and Ronald Van Ham who started the research towards Lucy. Also Michaël Van Damme for his help, particularly on programming issues, Joris Naudet and the other members. Also the technicians Jean-Paul Schepens, André Plasschaert and Gabriël Van den Nest for the crucial help in the construction of Lucy and Thierry Lenoir for keeping the computers alive.

I also want to thank the people of the Vrije Universiteit Brussel, the Faculty of Engineering, the Polytechnische Kring, Liberaal Vlaams Studenten-Verbond, HVI,... I am very grateful to the people that have been with me to share this whole experience. They have stretched me academically and personally. My best friends come out of this splendid period. Thanks Ken, Rianne, Sophie VH, Niels, Sophie H, Jan, Daft, Xtel, Jean-Marc, Nathalie, Nancy, David, Olivier, Rina, Laurent, Jean-Jacques, Eva, Peter, Stéphanie, Emma... You have always been a great support for me.

Thanks to Kazuhito Yokoi I had the opportunity to work for 6 weeks on the humanoid robot HRP-2 at the ISRI/AIST-CNRS Joint Japanese-French Robotics Laboratory. It was a wonderful experience thanks to Olivier Stasse and the other members of the lab.

I would also like to thank the jury members of my PhD: Jean-Paul Laumond, Martijn Wisse, Yvan Baudoin, Rik Pintelon, Jacques Tiberghien, Philippe Lataire and Patrick Kool for their comments and suggestions to improve the dissertation.

Sidney Appelboom learned me as swimming coach to push my boundaries and helped me to overstep my own limits. His training schedules were sometimes extremely hard, some said they were crazy. Although I never reached the top, they were important lessons for me. So many thanks Sid!

Finally, my most profound thanks are to my parents and the other members of the family, especially my brother, oma, opa and bompa for their love, support and understanding throughout the years. My mother has spent many hours to tinker with me; my father helped me a lot building model boats and airplanes. They both were convinced one cannot start explaining science and technology at an early enough stage. Probably these were the first steps towards robotics. They showed that science and technology can be fun and I hope the work done for Lucy and my efforts explaining it to children has inspired many to start a career in exact or applied sciences.

Brussels Bram Vanderborght
January 2010

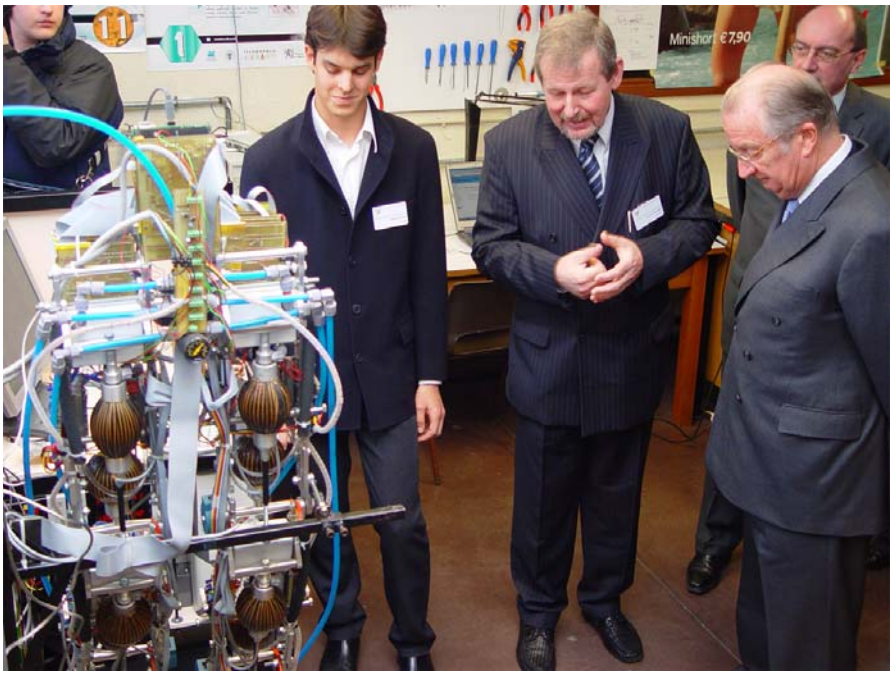

Fig. 0.1 Visit of His Majesty King Albert II of Belgium.

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