Project no. 231688

LOCOMORPH

Robust Robotic Locomotion and Movements Through Morphology and Morphosis

Small or Medium-Scale Focused Research Project

Seventh Framework Program, Theme: ICT-2007.8.5

Future and Emerging Technologies (FET), Embodied Intelligence

Start date: 1 February 2009 – Duration: 50 months

D3.4 – Two robots exhibiting all of the integrated results to be shown in Demonstration 3

Due date: May 9, 2013

Actual submission date: May 9, 2013

Number of pages: 11

Project Consortium

Beneficiary no.	Beneficiary name	Short name
1 (Coordinator)	Universitaet Zurich	UZH
~~2~~	~~Friedrich-Schiller-Universitaet Jena~~	~~UJEN~~
3	Ecole Polytechnique Federale de Lausanne	EPFL
4	Syddansk Universitet	USD
5	Universiteit Antwerpen	UANT
6	Ryerson University	RU
7	Technische Universitaet Darmstadt	TUD

Dissemination Level

Project co-funded by the European Commission within the Seventh Framework Programme Dissemination Level		
PU	Public	X
PP	Restricted to other programme participants (including the Commission Services)	
RE	Restricted to a group specified by the consortium (including the Commission Services)	
CO	Confidential, only for members of the consortium (including the Commission Services)	

Abstract

This deliverable presents the integration of our efforts from all WPs over all four years of the project into our final set of three robots. One is SpringyBot, which has been built with the LocoKit and which demonstrates the potential of this construction kit. The robot integrates results from evaluations conducted in the context of WP6. The second robot is the Zurich 2 robot (UZH2). The design represents a hardware implementation of the SLIP model and exhibits one of our key concepts - morphosis. The third robot, the Locomorph robot, is based on earlier designs of the project. It combines their advantages without inheriting their limitations. Furthermore, it embodies the efforts of all WPs over all four years in one final platform, and it is in a sense, the "flagship" of the series.

Introduction and Overview

This deliverable presents the integration of our efforts from all WPs over all four years of the project into our final set of three robots.

One is *SpringyBot*, which has been built with the LocoKit and which demonstrates the potential of this construction kit to serve as a scientific tool. Over the last years the robot has been improved continuously and has been evaluated at all demonstrations of WP6 (e.g., see Deliverable 6.3).

The second robot is the Zurich 2 robot (*UZH2*). The design represents a hardware implementation of the SLIP model. Due to the development of a new set of theoretical models (M-SLIP models) in WP4, the gap between this real-world platform and the theoretical models has been closed even further.

The third robot, the *Locomorph robot*, is based on earlier designs of the *UZH1* (see reports and deliverables of the previous years) and the *UZH2* of the project. It combines their advantages without inheriting their limitations. Furthermore, it embodies the efforts of all WPs over all four years in one final platform and it is in a sense, the "flagship" of the series.

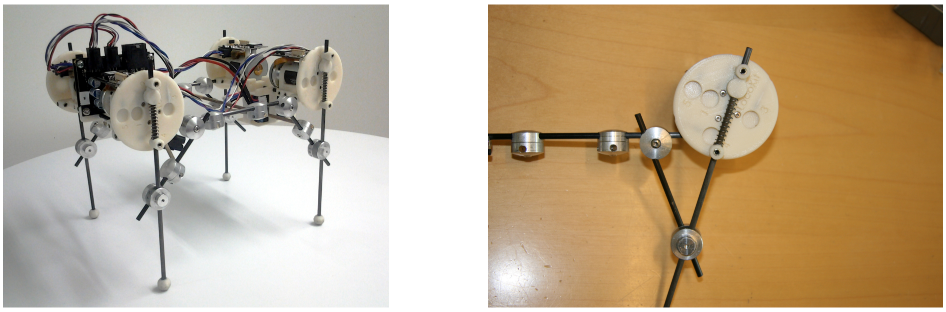
In the following sections, we describe the individual robots and we will point out which parts of our results over the last four years have been integrated in them.

SpringyBot

The SpringyBot is built out of the LocoKit and is based on the design principle of the UZH1 robot (developed in WP3 and presented in previous years). Over the last years the SpringyBot has gone through a process of iterative improvements, which were driven by two aspects:

First, the LocoKit parts have been improved continually by partner USD. The parts were optimized to find the smallest set of basic modules, which allow for a large variety of different robots. Furthermore, design details and the production process have changed to increase the durability of the elements. In addition, the electronics have been updated to drive stronger motors and to be able to implement a more sophisticated control framework in hardware and software. For more details we refer to deliverables D2.5 and D7.4.

Second, the robot has been improved based on the yearly evaluations in the context of the robot demonstrations of WP6. For example, the performance of SpringyBot has been improved drastically based on the obtained insights of the evaluation of the robot demonstration of year 2 (see, e.g., [2] or [3]). This demonstrates the success of our approach to use tools typically applied in biology and sport science, like high speed infrared cameras and force plates, to evaluate robots. The latest version of the *SpringyBot* represents the accumulated integration of number of iterative steps including work done in WP2, WP6, and WP3. Figure 1.1a shows the latest version of the robot.



(a) (b)

Figure 1.1: (a) latest version of the SpringyBot and (b) crank-slider mechanism implementation of the SpringyBot

As previously mentioned SpringyBot's morphology resembles the design idea developed for the UZH1 robot. Every leg has just one degree of freedom, which is a rotating disc driven by a single motor. A crank slider mechanism translates this rotational movement in a two dimensional leg trajectory. Figure 1.1b shows a picture of the implementation in the SpringyBot. One of the advantages of this design is the inherent energy efficiency (one of Locomorph's objectives). The motor can run continuously without having to accelerate and decelerate the whole leg in an alternating fashion.

In addition, the design resembles the M-SLIP model and, hence, reflects the integration of the theoretical models developed of WP4. The mass of the leg is concentrated at the hip. Every leg has a spring along the leg axis and due to the morphology of the robot (as a function of how the the crank slider mechanism is attached to the body) one can define the angle of attack. A direct advantage of this approach is that the control solutions developed in WP5 can be directly applied, since they are based on the same models.

Another part of the integration of the results of WP5 has been carried out by Rasmus Frostholm Petersen (student at USD). He implemented a central pattern generator based controller, which has been developed by partner EPFL. This points out again the high level of collaboration, which was present in the project.

Finally, the SpringyBot is a great example of how the LocoKit can be used to build legged robot and to use it as a tool for research. Partner USD has publish a number of papers, where they used the SpringyBot, see [1], [2], and [3].

The UHZ2 Robot

The design of the UZH2 robot is based on the idea to build a hardware template, which closely resembles our theoretical models (i.e., SLIP and M-SLIP). The design approach is the integration of our discussion in year 2 and the feedback from the reviewers. It includes the insights gained during our series of experiments with a number of different morphologies (see Deliverable D3.1). For more details on the design of UZH2 we refer to Deliverables D3.1 and D3.2 , and to the first and the second periodic report. The full robot can be seen in Figure 1.2.

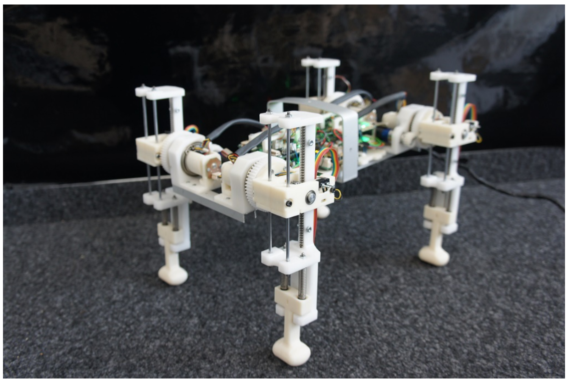


Figure 1.2: The latest version of the UZH2 robot.

The robot consists of four equal legs, which reflects our approach to have modular robots to enable investigation of different morphologies. Last year we demonstrated that our design, directly inspired by the SLIP model, exhibits similar properties as the theoretical model [5]. Hence, our approach to implement the theoretical template as a real physical platform was successful. Figure 1.3 shows one of the UZH2 legs on a boom. One can see that, as in the SLIP model, the center of mass is concentrated

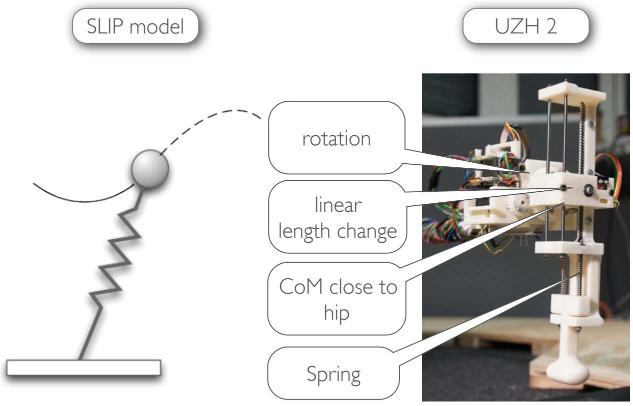
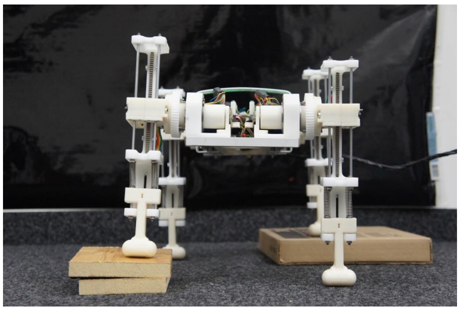
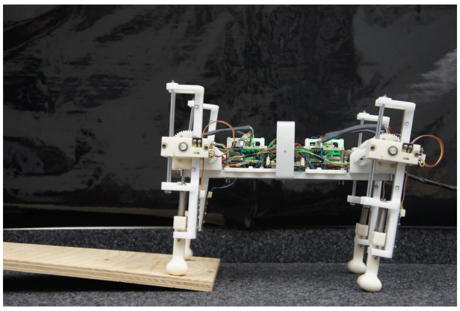


Figure 1.3: UZH2 and the resembling of the SLIP model .

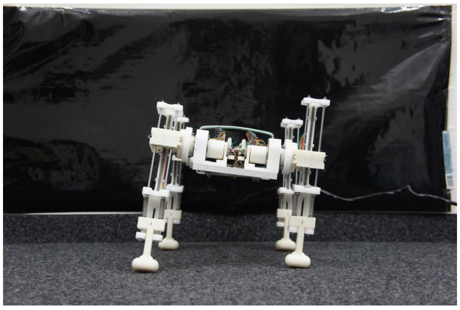
(mostly) at the hip and the leg has linear springs along the leg axis. Furthermore, the combination of the two degrees of freedom (one rotational and one linear) allow any desired leg trajectory. This setup enables the robot potentially to control the angle of attack. The degree of freedom, which changes the leg length, can, in addition, to be used as a way to adapt to different environments (e.g., rough terrain) or to adapt to a new task (e.g., to counterbalance external forces or to balance). Figure 1.4 shows a number of examples, how this capability could be potentially be used. The changeable leg length module is one of our hardware solutions to implement a change of morphology (i.e., voluntary morphosis) in robots (one of Locomorph objectives).



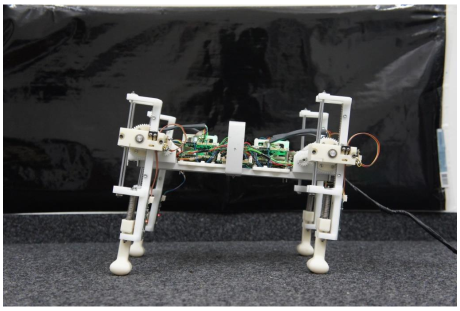
(a) on rough terrain



(b) correcting an inclination



(c) Move the center of mass to the side to withstand external forces



(d) Move center of mass to the back to withstand external forces.

Figure 1.4: Examples of how the changeable leg length module can be used to adapt its morphology to different environments and for different tasks (voluntary morphosis).

The Locomorph Robot

The Locomorph robot is the final robot of our series of robotic platforms developed over the course of the last four years. It embodies the accumulated knowledge and insights that we have gained within the project through experiments in WP3 and evaluations in WP6. Furthermore, it considers biological data from experiments we have conducted in WP4, and the theoretical models that have been developed, also in the context of WP4. In that sense one could say the Locomorph robot is the "flagship" of the project.

The Locomorph robot is the hardware manifestation of our *Locomorph approach* as described in Deliverable D7.3. The approach has emerged over the last years due to the strong collaboration between the partners of the project. Figure 1.5 shows the approach conceptually. It has a strong emphasize on generic theoretical models for locomotion, which we see as a pivotal point for the research on locomotion. All other research activities, like obtaining data from biological systems, developing control architectures, and also to building hardware platforms, are directly interacting with the theoretical models (for more details we refer to Deliverable 7.3).

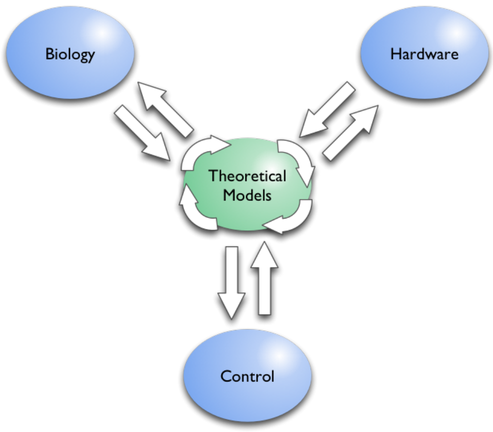


Figure 1.5: The Locomorph approach as described in D7.3

Hence, the motivation to develop the Locomorph robot was to obtain a flexible hardware platform to build physical realizations of our theoretical models with different levels of complexity. This enables us to validate the models and eventually improved them, e.g., to close further the gap between theory and real-world implementations in locomotion. Consequently, the design approach of the Locomorph robot is highly modular to allow investigation of a large number of research questions. Instead of having a fixed morphology to mimic a specific species, the Locomorph robot is designed to serve as modular robotic kit, which allows the implementation of a number of theoretical models with different degrees of complexity. For example, in Figure 1.6 the Locomorph robot is shown as a single leg, as bipedal unit on a boom, and as a quadruped. The corresponding models with increasing complexity can be seen in Figure 1.6 as well. The depicted models have been developed in the project in WP5.

We would like to emphasize the point that the described *Locomorph approach* is different to the traditional approach to build legged robots. Typically, inspired by a chosen role model (i.e., a chosen species to mimic) some kind of segmented legs are used. However, our novel research approach is driven by the goal to create a flexible, high performance modular robot system that can be used for the validation of a variety of models and to study the locomotion capabilities of these templates rather than of a specific animal. We believe that with such an abstraction of legged locomotion we will be able to obtain a more general understanding of underlying principles that apply to a variety of animals, rather than just to a specific one.

As one can see in Figure 1.5 the development of appropriate control solutions (as part of WP5) were also driven by a direct interaction with the theoretical models. Again, this means the developed control framework represents a generic control solution for locomotion, rather than being bound to a given morphology. Another consequence is that a direct implementation of the control on the Locomorph robot is possible.

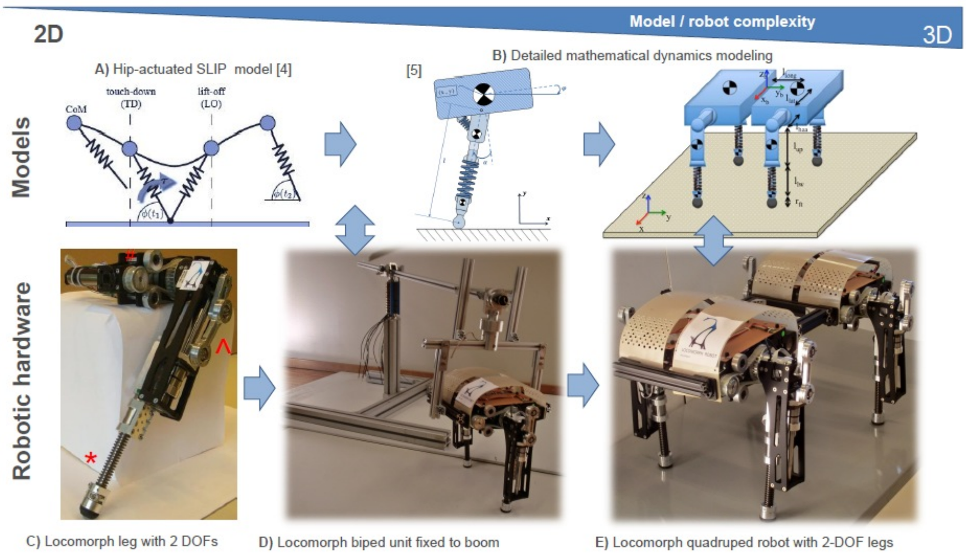


Figure 1.6: The modularity of the Locomorph robot and it's role as template for our theoretical models.

In Figure 1.6E we present a quadruped created from the Locomorph robot system with 2 degrees of freedom (DoFs) at each leg. The chosen leg design (1.6C) features a DoF for leg extension/contraction as well as a linear spring along the leg axis with the actuator. Like in the SLIP model the linear spring is used for the storage and release of energy within a gait cycle, but on the physical platform it serves also to protect the motor. The design enables a fast change of springs to facilitate the investigation of different stiffness values. The actuator uses a crank-slider mechanism that transforms the continuous rotation of a motor into a periodic leg extension/contraction. The robot further implements a second DoF for leg retraction/protraction that is actuated through a spring-loaded timing belt. Note that this is a design, which partly combines the advantages of the UZH1 and the UZH2 robots without inheriting their limitations. Hence, the Locomorph robot embodies the integration of previous robots built in Locomorph. The robot can also be equipped with a 3rd DoF, which allows for abduction/adduction. The robot is then able to switch from a dog like posture into a sprawling position as in salamanders. The presented legs can be connected through profiles (rigid or with compliant elements) to create bipedal units, which can be independently operated for studying bipedal running. Two and more bipedal units can be connected through stiff or flexible spine elements to form quadruped robots, or even robots with more than four legs.

Over the last year the robot design has been revised and optimized in a two stage process. We evaluated the first version (consisting of only two legs), we improved the design, and, finally, produced a second version. Right now we have three bipedal units. The design approach has been presented at the AMAM 2013 conference [4].

Bibliography

[1] Jørgen Christian Larsen, David Brandt, and Kasper Stoy. Locokit: A robot construction kit for studying and developing functional morphologies. In *From Animals to Animats 12*, pages 12–22. Springer, 2012.

[2] Jorgen Christian Larsen, Kasper Stoy, David Brandt, Sten Grimmer, and Martin Gross. Systematic, bottom-up robot design using a biomechanical experimental methodology. 2012.

[3] Jorgen Christian Larsen, Kasper Stoy, David Brandt, Sten Grimmer, and Martin Gross. Increased performance in a bottom-up designed robot by experimentally guided redesign. *Industrial Robot: An International Journal*, 40(3):8–8, 2013.

[4] Rico Moeckel, Soha Pouya, Christophe Maufroy, Frank Peuker, Alexandre Tuleu, Stéphane Bonardi, Massimo Vespignani, Sten Grimmer, Peter Aerts, Kristiaan D'Aout, Helmut Hauser, Lijin Aryananda, Rolf Pfeifer, Kasper Stoy, André Seyfarth, and Auke Jan Ijspeert. Locomorph robot system - towards legged modular robots with model-inspired morphology. *International Symposium on Adaptive Motion of Animals and Machines*, 2013.

[5] Farrukh Iqbal Sheikh, Helmut Hauser, Lijin Aryananda, Hung Vu Quy, and Rolf Pfeifer. Slip-model-compatible and bio-inspired robotic leg with reconfigurable length. In *The 5th International Symposium on Adaptive Motion of Animals and Machines (AMAM2011)*, October 2011.