A Closed Loop Walking Controller for a Biomimetic, Robotic Mouse

Master's Thesis in Informatics

Final Presentation

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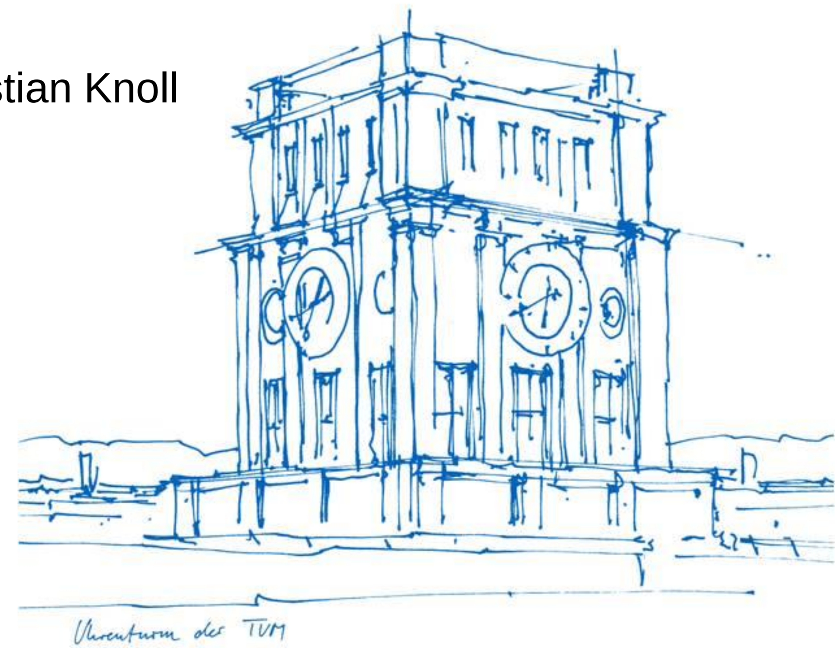


“Presumably our common interest is in examining biological phenomenology in the hope of gaining insight and inspiration for developing physical or composite bio-physical systems in the image of life.”

\- Otto Schmitt 1963

Agenda

Introduction
- Motivation and Goal
- History of NerMo
- Biomimetic Robots in Research

Sensor Integration
- Foot Pressure Sensors
- I2C Communication
- UART Communication

Analysis
- Walking without Ground Contact
- Walking on Even Ground
- Walking on Uneven Ground

Improvements
- Initial Position Control

Outlook
- Lessons Learned
- Conclusion
- Outlook

Motivation and Goal

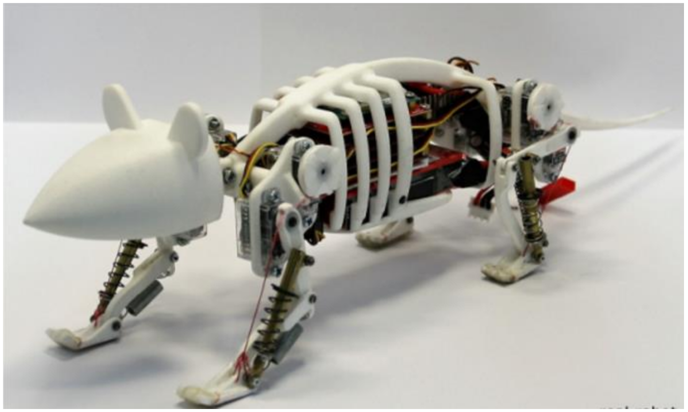
Overall motivation and goal for the Neurorobotic Mouse (NerMo):

- Greater understanding of nature
- Interaction with “biological counterpart“ (Lucas 2017)

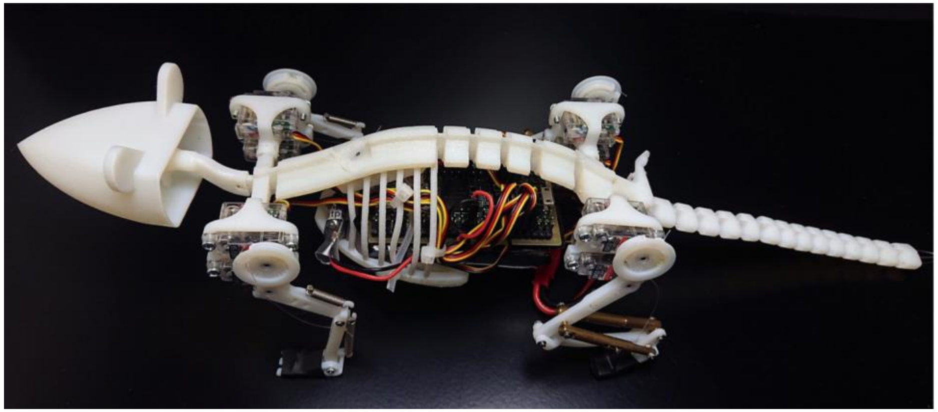
For this thesis:

- Sensor integration
- Improving NerMo’s biomimetic locomotion
- (“*A Closed Loop Walking Controller for a Biomimetic, Robotic Mouse*”)

History of NerMo



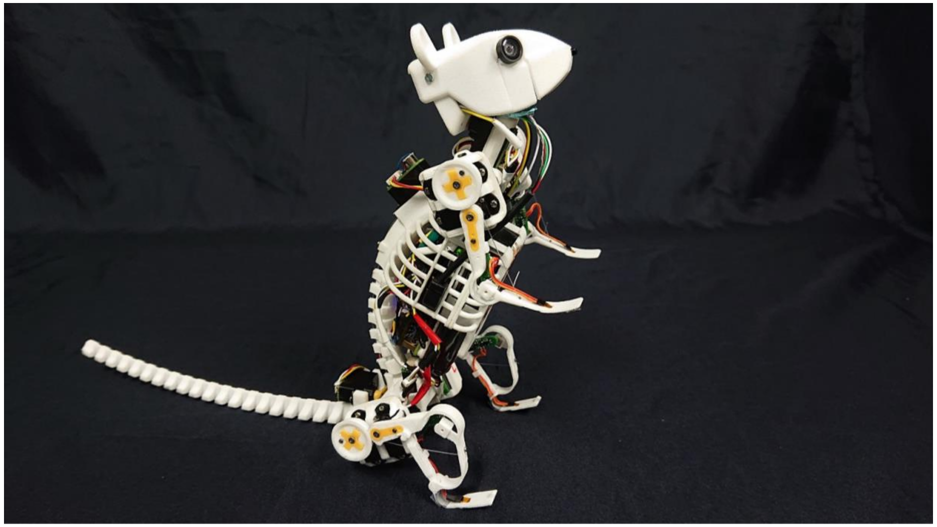
P. Lucas. “Design, Construction and Validation of a Life-Size Robot Model for Biomimetic Locomotion in Small Mammals”. MA thesis. TUM, 2017.



P. Lucas, S. Oota, J. Conradt, and A. Knoll. “Development of the Neurorobotic Mouse”. In: Proceedings IEEE International Conference on Cyborgs and Bionic Systems. Munich, Germany, 2019.

Version 4:

- Complete re-design
- 13 DOF
- 26 sensors
- Digital twin in NRP



P. Lucas, S. Oota, J. Conradt, and A. Knoll. “Development of the Neurorobotic Mouse”. In: Proceedings IEEE International Conference on Cyborgs and Bionic Systems. Munich, Germany, 2019.

Biomimetic Robots in Research

Education and Human Interaction

- MIRO

Sensing and Actuating

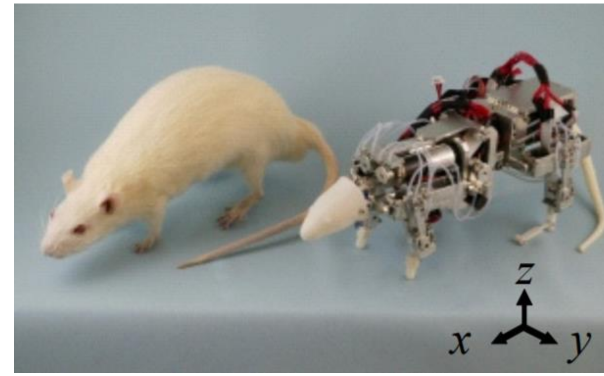
- Whiskerbot
- Gecko

Quadrupeds

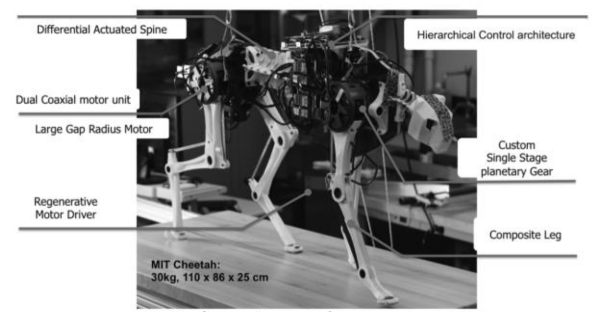
- MIT’s Cheetah
- Waseda Rat

Gait Control of Quadruped Robots

- Spot
- Mini Cheetah



H. Ishii, Y. Masuda, S. Miyagishima, S. Fumino, A. Takanishi, C. Laschi, B. Mazzolai, V. Mattoli, and P. Dario. “Design and development of biomimetic quadruped robot for behavior studies of rats and mice”.



H.-W. Park and S. Kim. “The MIT Cheetah, an Electrically-Powered Quadrupedal Robot for High-speed Running”.

E. C. Collins, T. J. Prescott, B. Mitchinson, and S. Conran. “MIRO: A Versatile Biomimetic Edutainment Robot”

B. Dynamics. Spot. 11.08.2020. url: https://www.bostondynamics.com/spot.

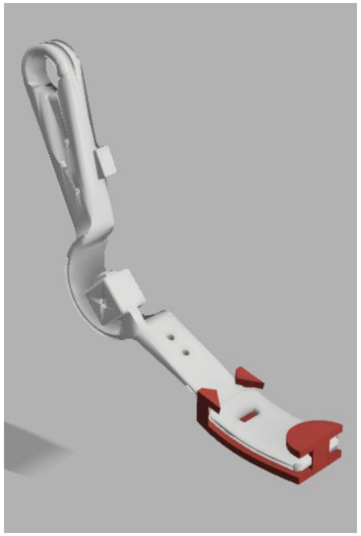
Foot Pressure Sensors

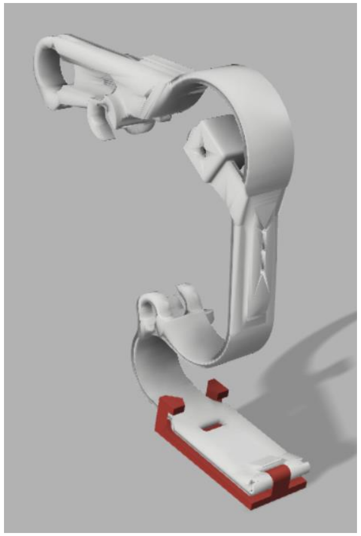
Thin-film pressure sensor

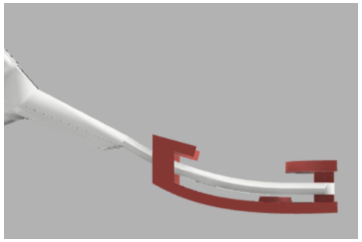
10g - 200g **selective** pressure

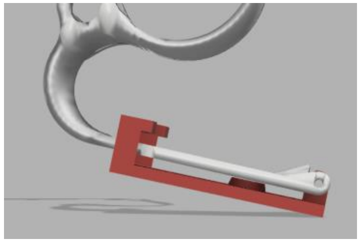
>> 200g **non-selective** pressure

Solution: 3D printed shoes

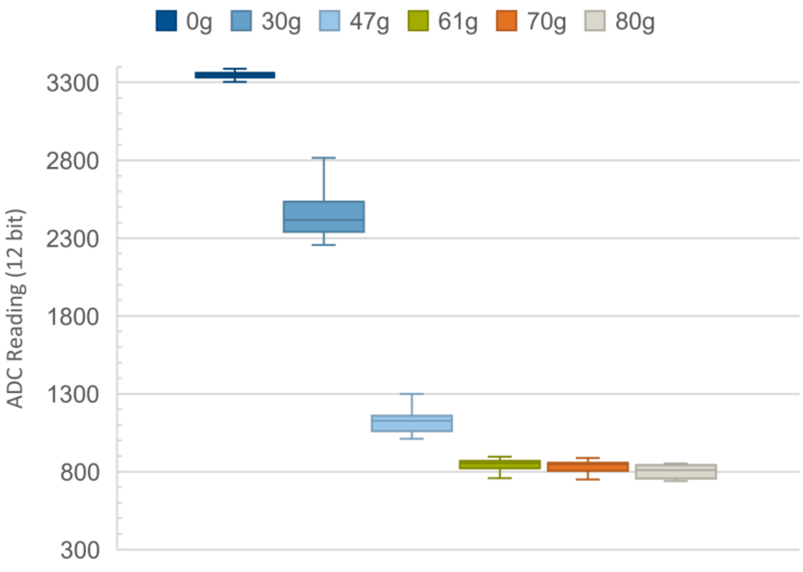






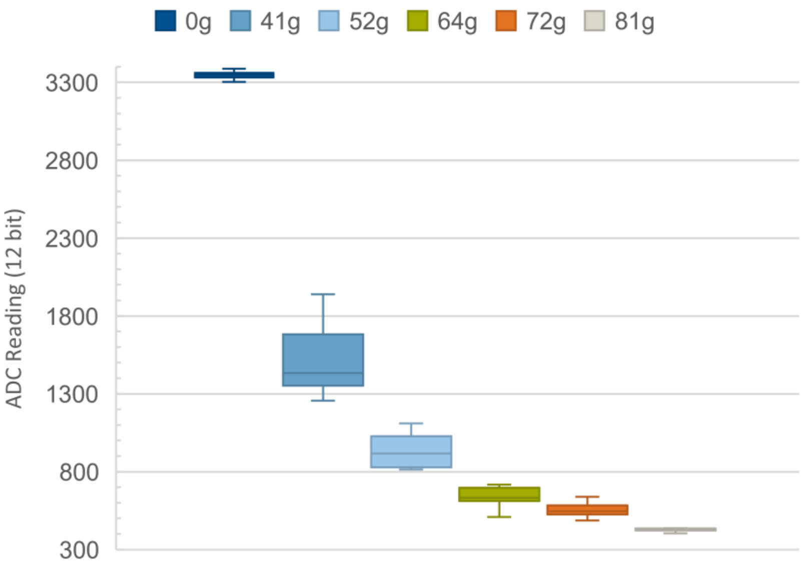


Foot Pressure Sensors



Front-leg setup

- Further improvements needed



Hind-leg setup

- Quite stable
- Sometimes bearing issues

I2C Communication

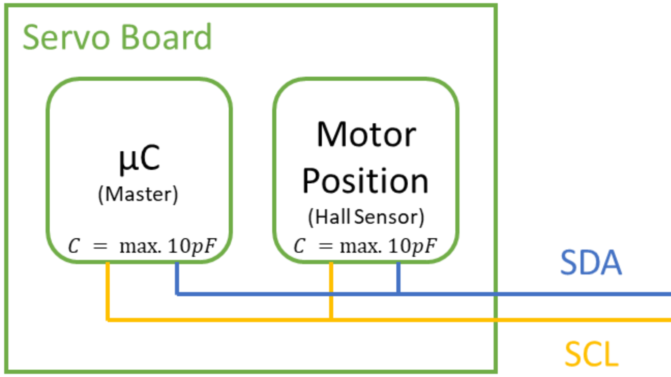
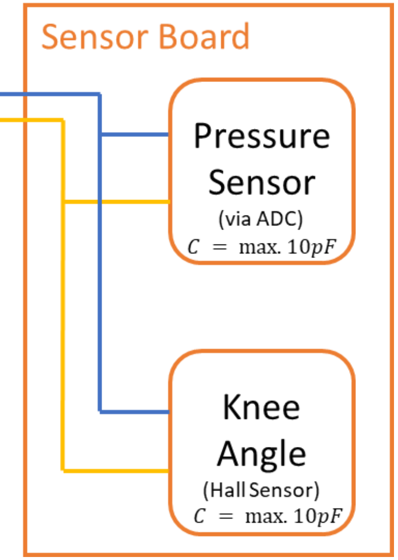
Simple sensor integration

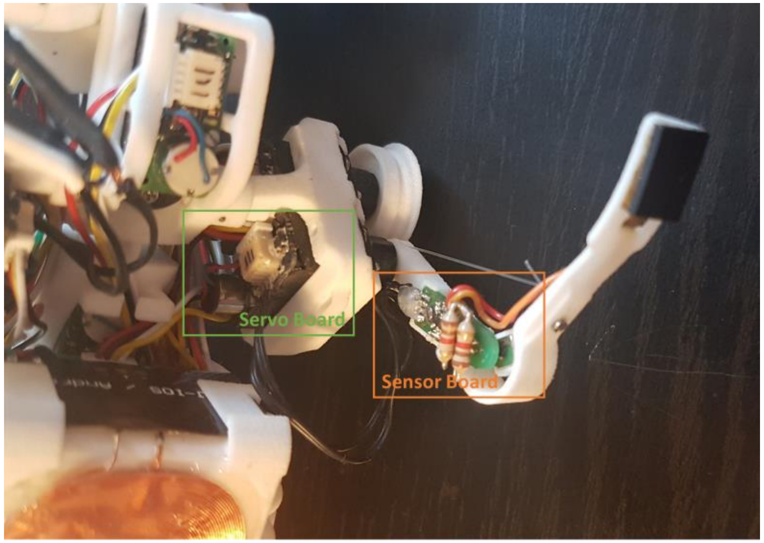
- Servo motor position
- Pressure sensor
- Knee angle sensor

Identical setup for each leg

I2C fast mode

µC as master



I2C Timings

Initial problems

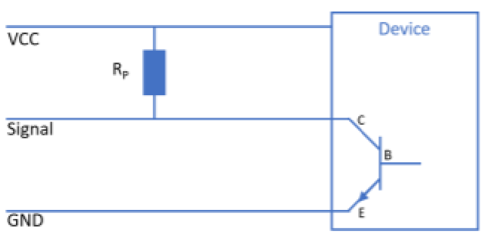
- Long rise time (internal pull-up resistors)
- Short HIGH time
- Long LOW time
- Short data setup time
- 1.8 V signal

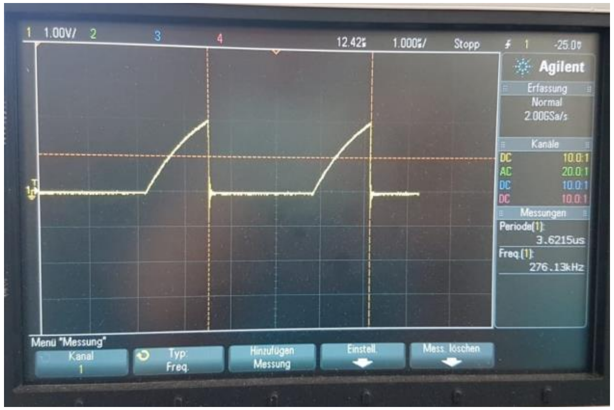
→ Changed to I2C fast mode specification

Pull-up resistor sizing

$$R_P(min) = \frac{V_{CC} - V_{OL}(max)}{I_{OL}}$$

$$R_P(max) = \frac{t_R}{\Big(ln(1-30\%) - ln(1-70\%)\Big) \cdot C_B}$$



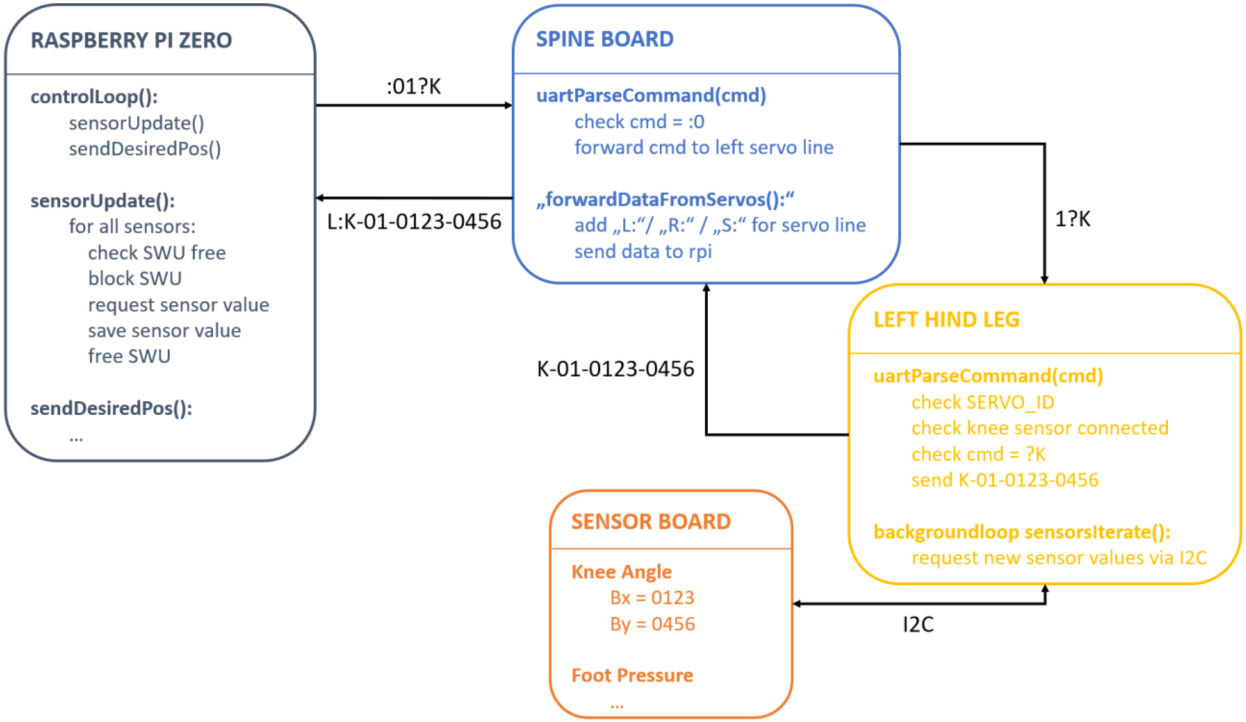


UART Communication

Inner-NerMo communication (set servo motor position, request sensor value etc.)

Communication via UART and SWU with collision avoidance

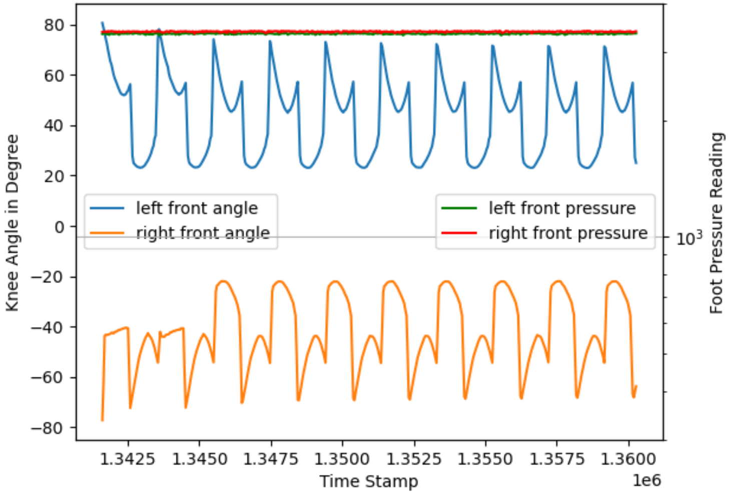
Implementation allows reply within 2,35 ms

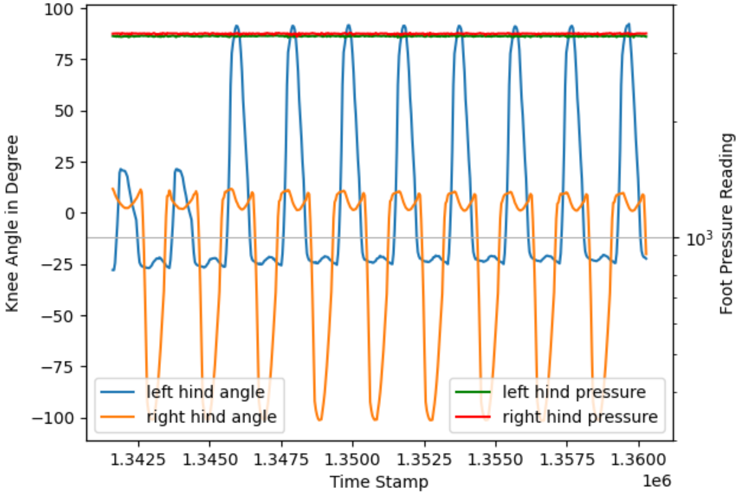


Walking without Ground Contact

Baseline for later comparison

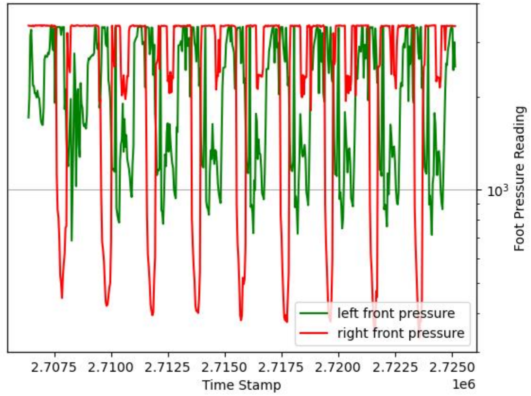
Besides bug cyclic and symmetric

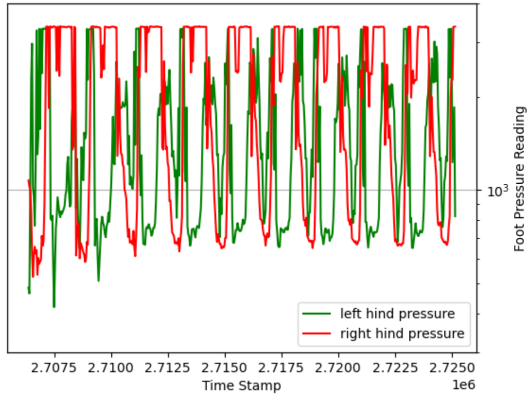




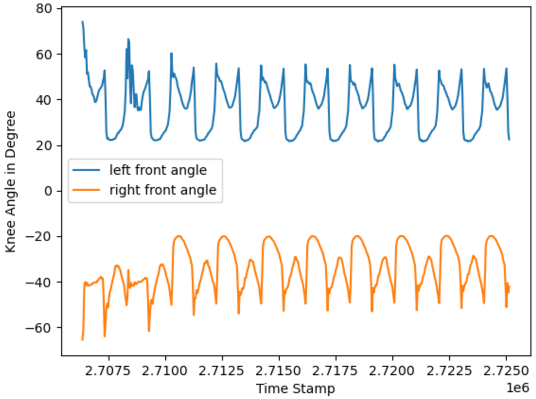
Walking on Even Ground

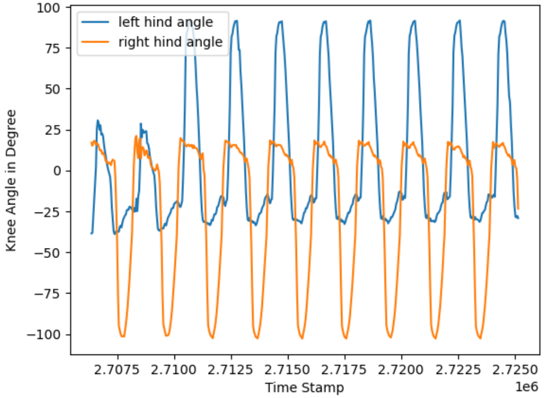
Foot pressure only as basic ground contact trigger





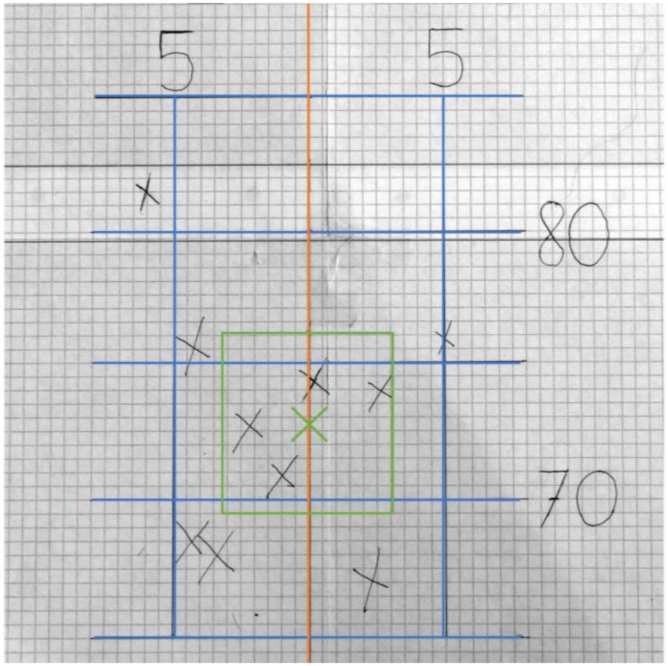
Smaller spikes due to load

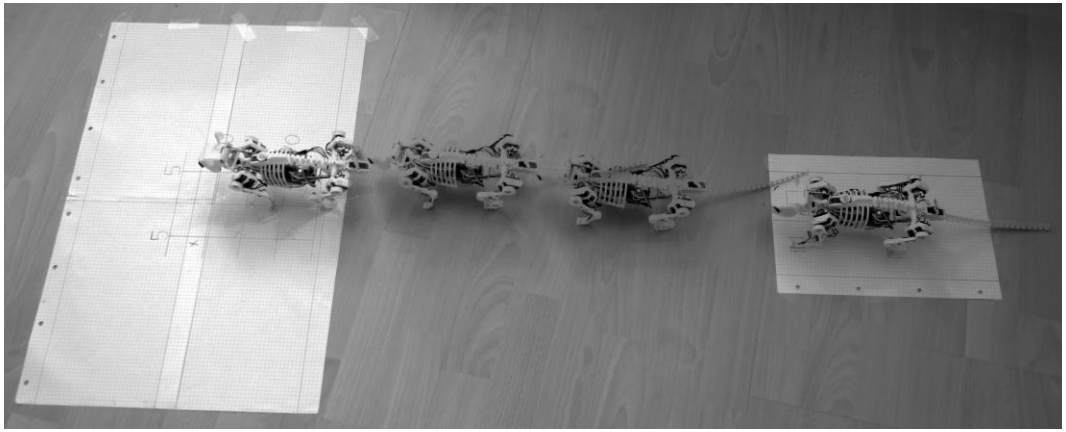




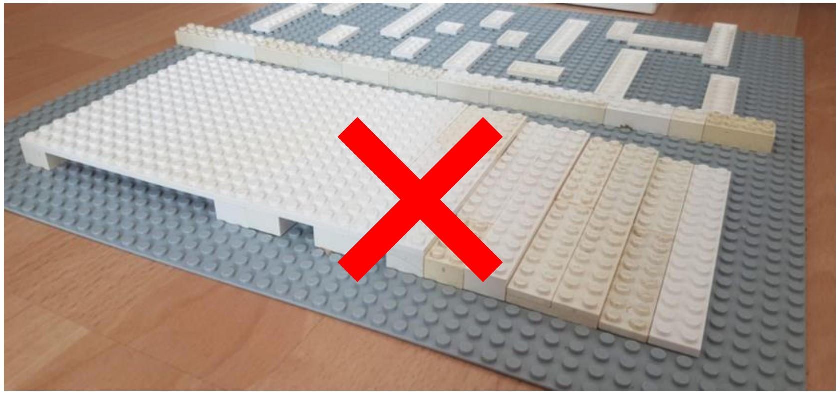
Repeatability of a Trajectory

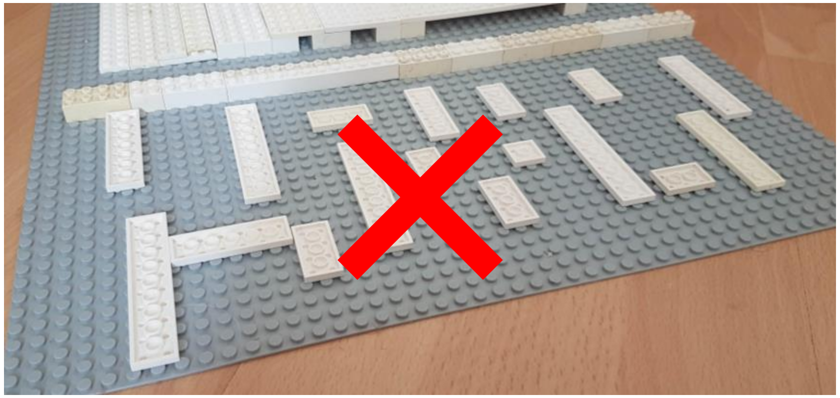
Walking straight for 10 steps





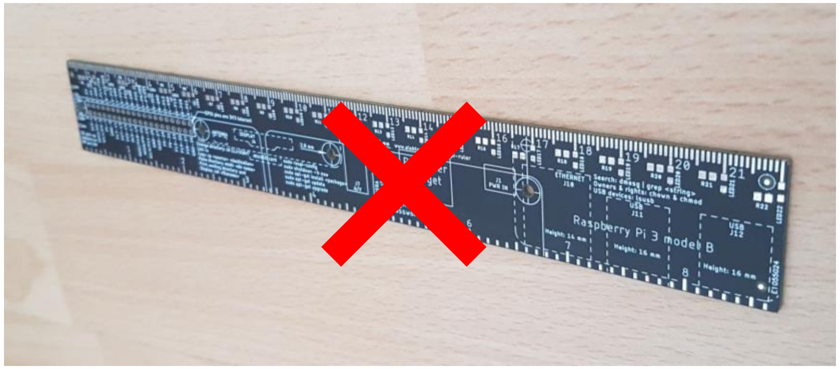
Walking on Uneven Ground





Possible / needed improvements

- Re-design legs for higher lift
- Better durability of legs
- Optimize trajectory



Initial Position Control

Improving locomotion by better initial setup

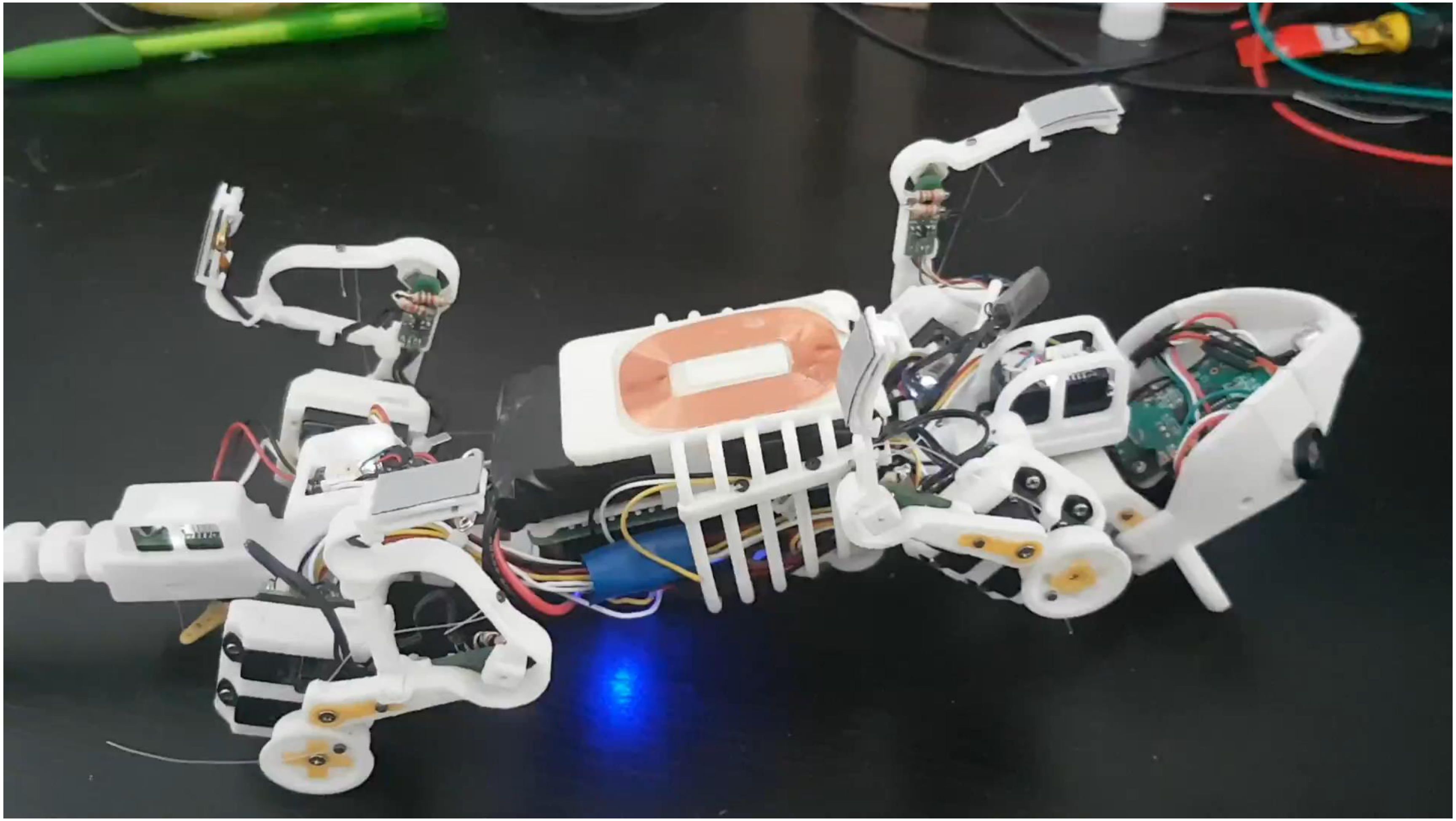
Better equals to:

- More symmetric
- Well defined knee angles
- Faster and simpler setup

Adaptive P-control with error management

Not fully tested yet due to broken servo motor

Initial Position Control



Lessons Learned

Tendons

- Solid nylon tendons rip often
- Mounting with screws worsens the behaviour

Circuit Boards

- Transistors to switch sensors on / off
- External pull-up resistors

3D Printing

- Precision and durability → material selection
- Especially for flexible parts

Cabling and Connections

- Small solder pads rip often (not repairable)
- Plug-in connections

Conclusion

Working with hardware is unpredictable, but also diverse and exciting!

Major improvements of NerMo to now allow further research biomimetic locomotion

Sensor Integration

- Knee angle sensor
- Foot pressure sensor
- Tested and documented in detail

Inner-NerMo communication

- I2C (Sensor- / Servo board)
- UART (RPI / Spine board)
- SWU (Spine- / Servo board)

Analysis of current state

- Without ground contact
- With ground contact
- On uneven ground

Improving locomotion

- Initial setup controller
- Suggestions for improvements

Outlook

Foot pressure sensors

- Trigger based control

IMU

- 9-axis with digital motion processor

Controller

- Only possible after further improving NerMo
- Uneven ground or more difficult terrain as goal

Re-design legs:

- fast worn through
- include foot pressure sensor to the design (e.g. shoes)
- ground clearance and height the feet can be lifted -> uneven ground

Re-think tendons:

- screws often tear tendons
- nylon wires often rip
- maybe test braided cords
- glue for fixing

Circuit boards:

- transistors to (re-)start sensors --> faster start-up times
- pull-up resistors for leg I2C bus and for IMU
- maybe smaller DC-DC converter on spine board as voltage source
- Alex: reduce signal oscillations

Cabling:

- solder pads are ripping off the servo boards too often (servo board to sensor board connection)
- same for the foot pressure sensor to sensor board connection when the cable is not long enough
- bigger slots for mounting the servo motors as they only fit without the connection cables to the sensor board

Changed parts:

- voltage regulators are now 3V (NCP553SQ30T1) not only on the servo board, but also sensor board
- changed from TLV493D-A1B6 to TLE493D-A2B6 as sensor on the sensor board because it allows slower start times (no change needed if transistor to start as on servo board, but then I2C code must be changed and address reconfigured)

https://github.com/jgenwo/NerMo2020