UNIVERSITÄT ZU LÜBECK

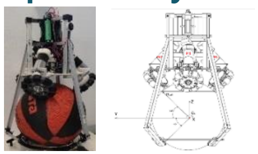
Student Projects

Institut für Medizinische Elektrotechnik

MPC and Path Planning of a Ballbot

Project Summary

Controlling a ballbot from a **digital twin** design remains challenging. The project aims to integrate an equivalent nonlinear system embedding, e.g., **linear parameter varying (LPV)** along with **nonlinear model predictive control (NMPC)** to enable **real-time balancing and motion** planning through **complex safety-aware environments**.



Digital twin of a ballbot

Project Types

- **BA** thesis – 3 months
- **MA** thesis – 6 months
- **Praktikum** – (3->6) months

Project Potential Objectives concerning time/level and will

- **Studying** the fundamentals of MPC and nonlinear embeddings
- **Investigating** the dynamics of such a challenging system
- **Data-driven model discovery** and system identification
- **Online optimization** tools for **real-time** implementation
- **Theoretical analysis** on **stability & recursive feasibility**

Required Qualifications

- Basic courses in automatic control
- Programming skills, e.g., Matlab/Python/C++
- Motivation for using Infineon/Raspberry Pi hardware

Contact

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Detailed Description

A ball balancing robot, also known as a ballbot, is a dynamically-stable mobile robot designed to balance on a single spherical wheel (e.g., a ball). Through its single contact point with the ground, a **ballbot is omnidirectional and thus exceptionally agile, maneuverable**, and **organic in motion** compared to other ground vehicles. **Its dynamic stability improves navigability in narrow, crowded, and busy environments.**

Nonlinear plant (model)

$$\dot{x}(t) = f(x(t), u(t)) \xrightarrow[x_k = k\Delta t]{\textbf{LPV}}$$

$$x_{k+1} = A(p_k)x_k + B(p_k)u_k, \;\; k = 1, \ldots$$

Prediction $x_{i|k}$: the i^{th} prediction at time k

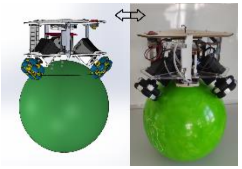
State & input constraint sets $\mathbb{X},\ \mathbb{X}_f,\ \mathbb{U}$

MPC can handle physical constraints compared to other control methods.

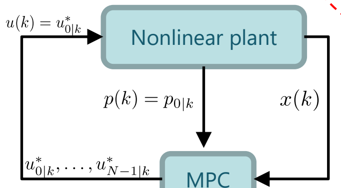
NMPC as Quadratic Program (QP)

$$\min_{u_{i|k}} \sum_{i=0}^{N-1} \ell(x_{i|k}, u_{i|k}) + \ell_f(x_{N|k})$$

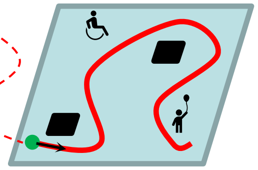
$$\begin{aligned} \text{subject to } & x_{i|k} \in \mathbb{X},\ i = 1, \ldots, N-1 \\ & u_{i|k} \in \mathbb{U},\ i = 1, \ldots, N-1 \\ & x_{i+1|k} = A(p_{i|k})x_{i|k} + B(p_{i|k})u_{i|k} \\ & x_{0|k} = x(k) \\ & x_{N|k} \in \mathbb{X}_f \end{aligned}$$



The new IME ballbot



Modeling & Control



Balancing & Motion

Selected References

- M. Studt, I. Zhavzharov and H. S. Abbas, "Parameter Identification and LQR/MPC Balancing Control of a Ballbot," 2022 European Control Conference (ECC), London, United Kingdom, 2022, pp. 1315-1321, doi: 10.23919/ECC55457.2022.9837996.
- T. Fischer, I. Zhavzharov, D. S. Karachalios, and H. S. Abbas, " In preparation "