Topic: Optimal Control Radar Tracking

Instrumented gait analysis is important in assessing the progression and status of various health conditions, the rehabilitation process, and quantifying performance in sports and fitness domains [1]. Tailored treatments can be designed to benefit the patients with the help of gait analysis results [2]. Currently, gait is usually recorded with either inertial measurement units (IMUs) or Optical motion capturing (OMC). When working with IMUs their exact positioning is important, and the relative position in space cannot be estimated. Issues with OMC are high equipment costs and complex setup, and clothing and poor lighting can affect the result [3, 4]. A promising approach is the use of Doppler radar, which provides continuous, unobtrusive, and contactless gait observation and analysis. However, the produced range-Doppler maps do not provide an intuitive visualization of the gait kinematics and therefore spatiotemporal parameters, such as stride time or the swing phase of individual legs, need to be methodically extracted [3].

Previous research has shown that optimal control simulations from marker tracking and ground reaction force data [4], as well as from IMUs [5] can be used to effectively estimate gait kinematics. Optimal control is a gradient-based optimization problem that aims to minimize an objective function while respecting dynamics constraints [4]. Based on this, the aim is to formulate an optimal control problem with radar tracking as the objective. The tracking objective is based on simulating Frequency Modulated Continuous Wave (FMCW) radar with a raytracer [6]. The simulated range-Doppler map is then compared to a recorded range-Doppler map. In previous works, the optimal control simulations with a radar tracking objective have converged successfully. However, finite gradients were used, and therefore, the function had to be evaluated often. This resulted in a runtime of approximately 50-70 hours and did not yield realistic results.

Therefore, this work aims to reduce the simulation's runtime by making the radar objective differentiable. Furthermore, as the ideal weighting between radar and effort objective terms is unknown, they will be systematically determined, including an adaptation of the radar sampling strategy. Lastly, the application on recorded FMCW radar data will be tested.

The proposed work consists of the following parts:

- Literature research regarding existing approaches of algorithms, evaluation metrics, and applicability of previous findings
- Creation of a differentiable radar-tracking objective and runtime evaluation
- Systematic determination of objective weights and loss functions
- Optional: Proof-of-concept validation against OMC

The thesis must contain a detailed description of all developed and used algorithms as well as a profound result evaluation and discussion. The implemented code has to be documented and provided. An extended research on literature, existing patents and related work in the corresponding areas has to be performed.

Advisors: Markus Gambietz, M. Sc., Maximilian Stahlke, M. Sc., Christian Schüßler, M. Eng., Prof. Dr. Anne Koelewijn

Student: Anne Dröge

Start—End: 15.11.2023 – 15.04.2023

References

[1] Abdul Saboor, Triin Kask, Alar Kuusik, Muhammad Mahtab Alam, Yannick Le Moullec, Imran Khan Niazi, Ahmed Zoha, and Rizwan Ahmad. Latest Research Trends in Gait Analysis Using Wearable Sensors and Machine Learning: A Systematic Review. *IEEE Access* 2020;8:167830. Published 2020 Aug 22.

[2] Abdul Aziz Hulleck, Dhanya Menoth Mohan, Nada Abdallah, Marwan El Rich, and Kinda Khalaf. Present and future of gait assessment in clinical practice: Towards the application of novel trends and technologies. *Frontiers in Medical Technology* 2022;4:901331. Published 2022 Dec 16.

[3] Ann-Kathrin Seifert, Martin Grimmer, and Abdelhak M. Zoubir. Doppler Radar for the Extraction of Biomechanical Parameters in Gait Analysis. *IEEE Journal of Biomedical and Health Informatics* 2021;25(2);547-558. Published 2021 Feb 5.

[4] Marlies Nitschke, Robert Marzilger, Sigrid Leyendecker, Bjoern M Eskofier, and Anne D Koelewijn. Change the direction: 3D optimal control simulation by directly tracking marker and ground reaction force data. *PeerJ*. 2023;11:e14852. Published 2023 Feb 7.

[5] Eva Dorschky, Marlies Nitschke, Ann-Kristin Seifer, Antonie J van den Bogert, and Bjoern M Eskofier. Estimation of gait kinematics and kinetics from inertial sensor data using optimal control of musculoskeletal models. *Journal of biomechanics.* 2019;95:109278. Published 2019 Oct 11.

[6] Christian Schüßler, Marcel Hoffmann, Johanna Braeunig, Ingrid Ulimann, Randolf Ebelt, and Martin Vossiek. A Realistic Radar Ray Tracing Simulator for Large MIMO-Arrays in Automotive Environments*. IEEE Journal of Microwaves* 2021;4; 962. Published 2021 Sept 9.