Nao Devils
Team Description Paper for RoboCup 2025
– Standard Platform League –

Arne Moos and Diana Kleingarn

Robotics Research Institute, TU Dortmund University
Otto-Hahn-Str. 8, 44227 Dortmund, Germany
naodevils.etit@tu-dortmund.de
https://naodevils.de/

1 Team Information

Team name:	Nao Devils
Team leader(s):	Arne Moos
Team contact email address:	naodevils.etit@tu-dortmund.de
Team website URL:	https://naodevils.de/
Country of origin:	Germany
University/company affiliation(s):	TU Dortmund University

2 Code Usage

The robotic framework used by the team *Nao Devils*[1] is based on the code release 2015 of team *B-Human*[2]. We want to thank the team *B-Human* for their great work developing their framework, which provides the base for our own developed modules. Compared to the 2015 code release of team *B-Human* we changed or adapted nearly all main and many minor modules with own contributions and further developed the whole infrastructure significantly. In addition, we have

[1] https://github.com/NaoDevils/CodeRelease
[2] https://github.com/bhuman/BHumanCodeRelease/releases/tag/coderelease2015

Fig. 1. The *Nao Devils* team members at RoboCup 2024. From left to right: Angelina Koch, Alexandra Cloodt, Diana Kleingarn, Tim Plotzki, Dominik Brämer, Aaron Larisch, Arne Moos, Leon Bless, Lisa Dasmann, Mahdokht Mohammadi, Robert Huber, and Thomas Klute.

been using the UKF developed by Team *Berlin United* for IMU filtering since 2018.

3 Own Contribution

The contributions mentioned in this section are mainly based on developments in the last year, and furthermore only outline our current plans for RoboCup 2025.

3.1 Motion

Fall Down Protection and Stand-up The fall-down protection introduced in previous years was further simplified and optimized. To enhance modularity, the keyframe engine was redesigned to prevent duplication of similar movements by allowing the next keyframe to be specified dynamically. Chained keyframe motions, pre-generated in a tree-like structure, were utilized to streamline the assignment of fall-down protection, stand-up, interception, and release motions while debugging all possible motion decisions. Additionally, a statistical approach now selects the most effective stand-up chain and prevents repeated attempts if no version proves successful.

Kicking To enhance precise kicking, which is increasingly utilized during games and technical challenges, we are further developing an adjustable kick mechanism with customizable kick strength. Additionally, greater emphasis is being placed on in-walk kicks, which are now designed to be able to additionally activated within the upward phase of foot movements, enabling more spontaneous decision-making for kicks.

Joint Play/Deadband Compensation Upon detecting a reversal in the joint's movement, an extra offset equal to the pre-measured deadband is added to the commanded angle to take up the slack in the gears, ensuring immediate engagement. Additionally, the compensation is distributed across the surrounding joints to account for the deadband and minimize accumulated play in interconnected joints.

Angular Torso Velocity Compensation To maintain balance, a compensation for angular torso movements are implemented by adjusting the base velocity. Using a Kalman filter, the system estimates the torso's angular velocity and acceleration from gyroscope and accelerometer data, accounting for sensor delay in addition with self-tuning. If excessive velocity is detected, a step command is generated based on the torso height and angular velocity to restore stability.

Broken Joint Detector The development of the Broken Joint Detector is currently focused on enhancing its robustness and context-aware fault detection capabilities. As part of this ongoing work, an audio-based analysis using a neural network is being explored to identify anomalies through sound patterns, aiming to add an additional layer of diagnostic precision. The joint analysis is being refined to better utilize discrepancies in joint currents and joint errors. Furthermore, an environment-aware evaluator is introduced that enables the robot to assess its surroundings for conditions such as being on the ground, proximity to other robots, or being stuck in a goalpost. This evaluation information is subsequently used to prevent further damage to the robot and enabling safe movements even with broken joints.

Kinematic Chain The kinematic chain was systematically checked and refined to enhance the accuracy of kinematics calculations. During the review process, particular attention was given to identifying and resolving errors in earlier implementations. The newly developed kinematics is tested through forward and inverse calculation tests. These validation steps ensured that the updated approach is now both robust and reliable.

3.2 Perception

Ball Detection Building on the developments from last year, we significantly improved our ball perception pipeline by optimizing parallelization and early

rejections. We have further enhanced our ball detection system specifically in the lower camera, where we integrated a Hough Circle Transformation based on the field color segmentation to create better and more accurate hypotheses for balls. Additionally, by optimizing the used loss-functions together with new trainig data our neural network for ball classification and ball-center regression was fine tuned. To further improve robustness, we implemented an automatic missed-ball collection mechanism. This feature identifies hypotheses that were rejected but are part of a chain of positive detections, allowing us to infer with high accuracy the presence of an additional ball in such cases.

Robot and Jersey Color Detection We utilize a YOLO-based neural network to generate robot hypotheses in both the upper and lower camera images, which are then filtered by a classifier and refined using a bounding box regressor. The jersey color determination is based on classical pixel-counting combined with dynamically adjusted color tables that should no longer be precomputed for each team. Instead, these tables are predicted and updated throughout the game, particularly at the beginning, requiring only the main jersey colors to be specified initially. A segmentation model in the lower camera enhances perception by focusing on robot parts and balls, with this information extended to the upper camera despite asynchronous and unknown field-of-view overlap.

Whistle Detection and Voice Activity Detection The whistle detection system now integrates both previously employed strategies, which have been slightly modified and combined to enhance robustness. Additionally, the ambient noise level is continuously monitored to dynamically adjust the threshold for whistle detection. The Voice Activity Detection module identifies whether someone is speaking near the robot, allowing the sensitivity of the system to be adapted accordingly. An optimized whistle detection network has also been introduced. Furthermore, the estimation of the direction and distance of sound sources was verified. For more details on this aspect, refer to the paper "Direction and Distance Estimation of Whistle Events on a NAO Robot"[3].

Speech Recognition Currently ongoing developments in speech recognition technology for the Nao robot will aim to address challenges posed by limited resources and the use of inexpensive, noisy microphones. This research aims to enhance the robot's capability to interpret spoken commands and interactions, which will be essential for effective communication in dynamic environments, especially where Wi-Fi-based information transfer is limited.

Visual Referee Gesture Detection Our goal is to enhance the real-time gesture recognition system introduced in last year's visual referee requirements. This system reliably detects the referee's "up" gesture during the standby phase

[3] https://link.springer.com/book/9783031858581

of a game, even under challenging conditions such as poor lighting or the presence of people in the background. Additionally, we have developed a pose estimation network based on the RSN (Residual Steps Network) structure. The output of this network is subsequently processed by a recurrent neural network, which not only identifies specific gestures but also captures their temporal dynamics and stabilizes the pose estimation output. Particular emphasis is placed on recognizing gestures where the referee reaches their hand out to indicate team side determination, as newly required by the competition rules.

3.3 Infrastructure

Automated Software Testing in Simulation We integrated the scripting language Lua into the simulator, enabling the design of tailored scenarios to test robot skills and behaviors. Furthermore, we restructured parts of the simulator to facilitate compatibility testing between different software versions, thereby supporting more varied and thorough testing environments. To streamline analysis, a centralized dashboard is developed that displays key performance indices in an intuitive manner. This dashboard is automatically populated with results from test runs whenever changes are pushed to the master branch, ensuring continuous monitoring and evaluation of the robots performance.

Real-World Testing To validate robot performance in real-world conditions, simulation-based tests are extended to physical robots. External cameras are employed to accurately measure performance metrics. For efficient data processing, compact single-board computers with integrated AI accelerators and cameras are utilized, all of which can be easily deployed using Power over Ethernet (PoE). By integrating multiple cameras, it is possible to create a detailed representation of the real-world environment. This setup not only distributes computational load effectively but also provides diverse camera perspectives for more robust testing and analysis.

4 Unpublished Results

The *Nao Devils* have been competing in the Standard Platform League since 2009, utilizing the Nao platform. Starting from 2020, they have participated in events such as GORE 2021, RoboCup 2021, GORE 2022, RoboCup 2022, GORE 2023, RoboCup 2023, German Open 2024, and RoboCup 2024. Detailed results of these competitions are available at https://spl.robocup.org/events/, or summarized in Table 1, which provides an overview of the games played in the main 5vs5 or 7vs7 competition formats. Furthermore, the *Nao Devils* have actively taken part in most of the Technical Challenges in recent years and have consistently achieved second place in the overall ranking since 2020.

Throughout the year, we take part in several local workshops and events such as the RoHOW workshop in Hamburg, Germany.

In addition to RoboCup 2025, we plan to participate in the German Open 2025[4] end of March in Nuremberg, Germany.

5 Impact

The *Nao Devils* are actively organizing events/workshops for the SPL. With the (irregular) organization of the RoDeo as a workshop in Dortmund, Germany and as co-organizer of the German Open Replacement Event series, we have a great influence in preparing the teams for the annual RoboCup.

In addition, we have advanced the live-streaming of SPL games and together with *Berlin United*, the games can be viewed live with game overlays for the spectators and saved in high quality for the teams. A unified system is expected to yield live statistics for the games, intended to utilize our system with multiple AI-cameras used for our Real-World testing.

Also, in the area of custom firmware images for the Nao, our work led to teams being able to easily create binary images during the corona pandemic to quickly install their code on unknown robots, which could then be used without the team being on site and has led to several further developments and a high level of popularity.

With a perennial member in the Technical Committee, the team helps keeping the league moving forward.

In the field of education, we offer each year a one-year lasting project group in the master of computer science (25 credit points), in which the students are introduced to the Nao and have to master a RoboCup-related project with it. Afterwards, the students usually remain part of the team until they graduate and some of them also write their master's theses with us.

[4] https://robocup.de/german-open/

Competition	State	Ourselves	Opponent	Score
GORE 2021	Round 1	Nao Devils	**HTWK Robots**	2:**4**
GORE 2021	Round 2	Nao Devils	**B-Human**	0:**10**
GORE 2021	Round 3	**Nao Devils**	R-ZWEI-KICKERS	**10**:0
GORE 2021	Round 4	**Nao Devils**	Berlin United	**8**:0
GORE 2022	Round 1	Nao Devils	**HTWK Robots**	0:**4**
GORE 2022	Round 2	**Nao Devils**	HULKs	**10**:0
GORE 2022	Round 3	**Nao Devils**	SPQR Team	**2**:1
GORE 2022	Round 4	Nao Devils	RoboEireann	2:2
GORE 2022	Round 6	Nao Devils	**B-Human**	0:**7**
GORE 2022	Quarterfinals	Nao Devils	**Bembelbots**	1:**2**
RoboCup 2022	Round 1	**Nao Devils**	UT Austin Villa	**8**:0
RoboCup 2022	Round 2	**Nao Devils**	Bembelbots	**4**:0
RoboCup 2022	Round 3	Nao Devils	**B-Human**	0:**4**
RoboCup 2022	Round 5	Nao Devils	**HULKs**	1:**2**
RoboCup 2022	Quarterfinals	**Nao Devils**	HULKs	**3**:2
RoboCup 2022	Semifinals	Nao Devils	**HTWK Robots**	0:**4**
RoboCup 2022	Third Place	Nao Devils	**rUNSWift**	0:**1**
GORE 2023	Round 1	Nao Devils	**HTWK Robots**	1:**5**
GORE 2023	Round 2	**Nao Devils**	Bembelbots	**4**:0
GORE 2023	Round 3	**Nao Devils**	NomadZ	**8**:0
GORE 2023	Round 4	**Nao Devils**	R-ZWEI KICKERS	3:1
GORE 2023	Round 6	**Nao Devils**	Naova	**6**:0
GORE 2023	Quarterfinals	**Nao Devils**	Dutch Nao Team	**3**:0
GORE 2023	Semifinals	Nao Devils	**B-Human**	0:**10**
GORE 2023	Third Place	**Nao Devils**	R-ZWEI KICKERS	**4**:3
RoboCup 2023	CC Round 1	Nao Devils	HULKs	1:1
RoboCup 2023	CC Round 2	Nao Devils	**B-Human**	0:**10**
RoboCup 2023	CC Round 3	Nao Devils	SPQR Team	1:1
RoboCup 2023	CC Round 4	**Nao Devils**	Berlin United	**2**:0
RoboCup 2023	CC Round 6	**Nao Devils**	Bembelbots	**2**:0
RoboCup 2023	CC Quarterfinals	Nao Devils	**rUNSWift**	0:**3**
German Open 2024	Round 1	HTWK Robots	**Nao Devils**	0:**1**
German Open 2024	Round 3	**B-Human**	Nao Devils	**9**:0
German Open 2024	Round 4	**R-ZWEI KICKERS**	Nao Devils	**3**:2
German Open 2024	Round 5	**Nao Devils**	Dutch Nao Team	**10**:0
German Open 2024	Round 6	**Nao Devils**	Bembelbots	**5**:0
German Open 2024	Semifinals	**B-Human**	Nao Devils	**10**:0
German Open 2024	Third Place	**Nao Devils**	HULKs	**2**:0*
RoboCup 2024	CC Round 1	Nao Devils	**HULKs**	0:**7**
RoboCup 2024	CC Round 2	Nao Devils	Berlin United	0:0
RoboCup 2024	CC Round 3	Bembelbots	**Nao Devils**	1:**2**
RoboCup 2024	CC Round 4	**Nao Devils**	NomadZ	**6**:0
RoboCup 2024	CC Round 5	**B-Human**	Nao Devils	**10**:0
RoboCup 2024	CC Round 6	**HTWK Robots**	Nao Devils	**4**:0
RoboCup 2024	CC Round 7	**Nao Devils**	rUNSWift	**4**:0
RoboCup 2024	CC Quarterfinals	**RoboEireann**	Nao Devils	**1**:0

Table 1. Results in the main competition (5vs5 or 7vs7) of the *Nao Devils* from 2021 onwards.
* = *after penalty shootout*