The NUbots Team Description Paper 2026

Joe Bailey, Sebastian Brooker, Will Burgin, Clayton Carlon, Stephan Chalup, Lucinda Fien, Angelique Herfel, Kim Khang Hoang, Alexandre Mendes, Johanne Montano, Thomas O'Brien, Corah Oliver, Khaled Saleh, Mithun Sivanesan, Vincent Tumminello, and Hengning Xu

Newcastle Robotics Laboratory
College of Engineering, Science and Environment
The University of Newcastle, Callaghan 2308, Australia
nubots@newcastle.edu.au
https://nubook.nubots.net/

1 Lessons Learnt

From 2023 to 2025, the team spent much effort moving towards two new subcontrollers, the OpenCR at first, and the NUSense later on. The former in particular caused much instability since it affected the low-level operations of the robot, e.g. servo-commands. At the 2025 RoboCup, the team settled on the NUSense subcontroller which improved the stability somewhat after much fine-tuning and testing. These transitions not only caused instability in performance but also hampered development in other areas such as locomotion and gameplay. Now that the subcontroller is finalised, the team will ensure that it remains stable without sacrificing too many team-resources on maintaining it.

In the 2025 RoboCup, although the robots could walk fairly stably in a straight line, which was often enough to win against struggling teams or empty fields, they struggled with more advanced gameplay in order to effectively play against teams made up of more robots. Therefore, the team has realised that, having established the basic functionalities such as dribbling the ball forward, it must begin to develop more advanced tactics and behaviour to progress further into the competition. This progression also includes cooperation between robots.

Because of the introduction of heavier and taller K1 robots last year, the former Humanoid League had tighten the enforcement of contact-rules. As a result, all robots must be able to competently avoid other robots lest they are penalised or get a red card from the referee. Thus, the team needs to improve the robots' ability to avoid obstacles without jeopardising contention over the ball.

Last year, the team spent much time developing a kick of various methodologies, i.e. scripted key-frame animation, spline-based inverse-kinematics, and an in-step kick. The last of which was the most stable but even then not stable enough to warrant much use in games, only when deemed needed at the time. The robot's ability to kick is quite important in order to progress through more advanced games where passing the ball is important.

As the team progressed further into the competition and played in games in which the gameplay was more advanced, the robots lacked proper actions and behaviour during penalties, e.g. throw-ins. For example, the robot would often touch the ball when it was meant to wait. Therefore, the team will dedicate development to improving the behaviour during penalties now that the team has progressed.

2 Major Challenges

As lesson learnt, the team must develop more advanced gameplay. However, other than software to be developed, the main limitation in achieving such is the robot's locomotion. For example, the robots had trouble with finer, more dexterous locomotion, e.g. strafing to the side, turning on the spot, in order to better control the ball. Furthermore, the robots had wide turning arcs, and thus were not able to tightly avoid opponents, an essential ability learnt from last year.

A further limitation to more advanced gameplay is the fact that the robot lacks a strong yet reliable kick. Having exhausted all other possibilities, the team will explore the implementation of a kick based on RL as part of a broader overhaul of the robot's motion.

Sometimes, the robot would fall over again soon after having already gotten back up. This instability right after getting up can develop into a cycle of repeatedly falling over. At the moment, the robot's getting up is a simple keyframe animation with no feedback from sensors. Furthermore, the getting up will fail halfway through or earlier in the scripted animation; for example, the robot may fall backwards when going from lying supine to crouching. Because it is a single animation with no feedback from sensors, the robot would needless continue running the animation even when it has failed earlier in the script. It was also found that the robot would be leaning either too far forward or too far back when going from crouching to standing.

Although the robot can localise reasonably well when it sees enough field-features and landmarks, it often fails in edge-cases, particular when it is near the edge of the field and cannot see many features. Furthermore, the robot's localisation collapses after it has fallen and gotten itself back up.

In last year's RoboCup, the interior of the robot's torso was re-arranged to allow better spacing for components. Unfortunately, this modification made the neck mounting slightly loose such that the head would wobble when walking. Since this looseness was not accounted for in the kinematics of the neck and the head, it drastically affected the cameras' estimated position, which is used to reverse-project features in the robot's vision, and thus worsened the robot's ability to localise whilst walking.

At the 2025 RoboCup, whenever the robots fell, the necks would break, often because the screws came loose or the 3D-printed mounting sheared or shattered. This damage is largely because of a single mechanical point of failure in the robots neck.

With both a YOLOv11 vision system[5] and a non-linear optimisation for localisation, among many other burdens, the robot's computer is close to its computational limit. Furthermore, the team is not even taking full advantage of an optimised toolchain, instead using a generic toolchain.

3 Planned Changes and their Status

The team is looking to replace the robot's motion with reinforcement-learning (RL) in order to improve the robot's locomotion, particularly in strafing and turning. That way, the robot can perform tighter and finer movements to better control the ball. The team has set up a MuJoCo simulation-environment and started some preliminary training of policies. The team has also begun to develop a software-module to integrate the RL engine on the robot locally.

In anticipation for more advanced gameplay, the team has been working on the ability to plan an optimal path so that the robot can dribble the ball around an opponent. So far, the algorithm has been tested in the *Webots* simulation-environment. It needs further testing on the real robot.

In order to make the robot get up more stably, the team is investigating more dynamic motions rather than a basic scripted animation. At the moment, the team is developing a prototype module that breaks the animation up into segments, each a smaller separate scripted animation. These segments are delimited in the software by checkpoints at which sensors are used to know whether the getting up has worked or failed. If failed, the whole getting up is restarted. As an extension, the team wishes to implement closed-loop dynamic control of the robot's torso as it goes from crouch to standing.

In order to tighten the neck and lessen the wobbling in the robot's vision as it walks, the team will improve the mechanical design of both the torso and the neck such that the head is rigid. The team has so far identified the area in the torso that needs structural reinforcement. Also, given the tendency for the necks to break when the robot falls, work has been underway to improve the mechanical design with a thicker and stronger design. The team has also considered a metal washer ring to help the screws clamp the mounting to the servo-motor.

To lighten the computational burden, the team has worked on an updated and optimised Docker image which is used to gather the needed libraries and toolchain and to build the binaries for the robot. It will be optimised specifically for the kind of computer that the robot has, namely an Intel NUC i7, such that the software runs much more smoothly and efficiently. The team has already developed most of this file and is in the last stages of testing and making sure that the libraries are working properly.

4 Contributions to RoboCup

The NUbots team have been active in the RoboCup community since 2002. Most recently, the team participated in 2025 in the Humanoid League kid-size division and finished at third place. Before that, the team have participated in the Four Legged League (2002-2007), the Standard Platform League (2008-2011), the Kid-Size Humanoid League (2012-2017, 2022-2024), and the Teen-Size Humanoid league (2018-2019). NUbots were the Four Legged League world champions in 2006. The team won the first Standard Platform League in 2008 as team NUManoid in collaboration with the National University of Maynooth, Ireland.

The team has taken part in outreach and publicity events for the host institution, namely the University of Newcastle, Australia. Team-members have given tours of the team's robotics laboratory to school pupils of various stages in both primary and secondary education in order to inspire interest in science, technology, engineering, and mathematics (STEM) for younger people.

Mid last year before leaving for Salvador, the team was interviewed and showcased on the local news, broadcasted in Newcastle, Australia and surrounding areas.[8] This televised appearance inspired interest and enthusiasm in robotics in the local community. The local masthead, the *Newcastle Herald* also reported on the team at the same time.[6]

The NUbots team has a long history of contributing to research in robotics, especially for RoboCup. Just last year, the team has published and presented research on zero-shot learning at the 2025 RoboCup Symposium which was chosen as an oral presentation among a select few.[1] It dealt with a technique to allow robots to classify untrained sounds in various environments picked up by a microphone. The team has also published three papers at the 2024 RoboCup symposium in Eindhoven.[11–13]

Furthermore, the team has worked on visual simultaneous localisation and mapping (VSLAM) on the robot to improve its localisation on the field. This research has been published and presented at the yearly Australasian Conference on Robotics and Automation (ACRA) in December 2025 along with one other paper.[3, 9]

In addition to published research, the team's RoboCup robot software [7], hardware [14], firmware [4], and debugging tools [2] are open source on GitHub.

Furthermore, the team maintains a comprehensive documentation resource in the form of a public website [10], providing detailed information about the hardware and software systems, as well as guides on various aspects of our systems. Not only does this resource aim to help new members of the team become acquainted with the systems, but it also aims to be useful to other RoboCup teams, as well as the wider robotics and AI community.

The team has also invented a Blender plugin that generates semi-synthetic images coupled with fully-annotated ground-truth segmentation maps [1]. Each image has a random allocation of robots, balls, and obstacles along with many variations in robot's kinematic pose and orientation. This tool is open on GitHub for anyone to use within the RoboCup community.

[1] The paper is awaiting proceedings-release and is titled "Zero-Shot Environmental Sound Classification Onboard a Resource-Constrained Robot" authored by Ysobel Sims, Alexandre Mendes, and Stephan Chalup.

References

1. Amos, M., Biddulph, A.: NUbots PBR pipeline repository. https://github.com/nubots/NUpbr, https://github.com/nubots/NUpbr
2. Annable, B., Houliston, T., Olejniczak, M., Paye, J., Biddulph, A., Court, L.: NUsight2 real-time web-based debugging utility code repository. https://github.com/NUbots/NUbots/tree/main/nusight2, https://github.com/nubots/NUsight2
3. Burgin, W., O'Brien, T.: Real-time humanoid state estimation with imu, kinematic odometry, and visual slam. In: Australasian Conference on Robotics and Automation (ACRA). Perth (2025)
4. Carlon, C., Montano, J.: NUbots firmware repository. https://github.com/nubots/NUcontroller, https://github.com/nubots/NUcontroller
5. Khanam, R., Hussain, M.: Yolov11: An overview of the key architectural enhancements (2024), https://arxiv.org/abs/2410.17725
6. McCarthy, S.: Meet the NUbots, the pint-sized robots taking their soccer skills to Brazil (Jul 2025), https://www.newcastleherald.com.au/story/9008692/robocup-bound-kevin-the-clumsy-yet-clever-bot/, section: Local News
7. Metcalfe, M., Fountain, J., Sugo, A., Houliston, T., Biddulph, A., Dabson, A., Johnson, T., Johnson, J., Annable, B., Nicklin, S., Fenn, S., Budden, D., Walker, J., Reitveld, J., Sims, Y., Young, T., Amos, M., Ginn, D., Hamiltons, K., II, J.P., Murtagh, C., de Koeyer, Y., Court, L., Craft, L., Carlyle, P., Hall, A., O'Brien, T., McFarlane, S.: NUbots robocup code repository. https://github.com/nubots/NUbots, https://github.com/nubots/NUbots
8. NBN: Newcastle | Hunter, https://www.nbnnews.com.au/2023/07/17/newcastle-hunter/
9. O'Brien, T.: Sampling-based predictive control for non-prehensile manipulation. In: Australasian Conference on Robotics and Automation (ACRA). Perth (2025)
10. Paye, J., Sims, Y.: NUbots handbook. https://github.com/NUbots/NUbook, https://github.com/NUbots/NUbook
11. Saleh, K., O'Brien, T., Sims, Y., Mendes, A., Chalup, S.: Efficient Sequence Model for Early Fall Detection of Humanoid Robots. In: Barros, E., Hanna, J.P., Okada, H., Torta, E. (eds.) RoboCup 2024: Robot World Cup XXVII. pp. 247–256. Springer Nature Switzerland, Cham (2025). https://doi.org/10.1007/978-3-031-85859-8_21
12. Sims, Y., Houliston, T., Amos, M., Biddulph, A., Tabac II, J., Noonan, A., Herfel, A., Bailey, J., Montano, J., O'Brien, T.: SoS: A Semi-Synthetic RoboCup Soccer Dataset for Visual Segmentation. In: Barros, E., Hanna, J.P., Okada, H., Torta, E. (eds.) RoboCup 2024: Robot World Cup XXVII. pp. 318–327. Springer Nature Switzerland, Cham (2025). https://doi.org/10.1007/978-3-031-85859-8_27
13. Sims, Y., Houliston, T., O'Brien, T., Mendes, A., Chalup, S.: The Director: A Composable Behaviour System with Soft Transitions. In: Barros, E., Hanna, J.P., Okada, H., Torta, E. (eds.) RoboCup 2024: Robot World Cup XXVII. pp. 328–338. Springer Nature Switzerland, Cham (2025). https://doi.org/10.1007/978-3-031-85859-8_28
14. Young, T., Biddulph, A.: NUbots hardware repository. https://github.com/nubots/NUware, https://github.com/nubots/NUware