The NUbots Team Description Paper 2018

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Abstract. The NUbots are the RoboCup team of the The University of Newcastle in Australia. In 2018 they play for the first time in the Teen-size Humanoid League using their self-printed robots based on the Igus-Nimbro design. In previous years the NUbots participated in the Standard Platform League (2002-2011) and the Kid-size Humanoid League (2012-2016). Over the past two years the NUbots have developed the NUClear software framework which is a modern software architecture specifically developed for robot projects. The NUbots' research addresses applications of machine learning, software engineering and computer vision. Their current research focus is Deep Learning. This paper provides an overview of the NUbots team, its software system and robot platform.

1 Introduction

For 15 years the Newcastle Robotics Laboratory has been hosting the NUbot robot soccer team as its central project. The NUbots previously competed at RoboCup in the Four-Legged League, the Standard Platform League and until 2017 in the Kid-Size Humanoid League. They now step-up to the Teen-size Humanoid League where they are a newcomer. The goal of the 2018 NUbot team is to demonstrate exciting state-of-the-art robot soccer skills using their modified Igus-Nimbro [2] based robot platform—the NUgus.

The following sections describe research and history of the NUbot team. Some of the material, such as the history and previous research, was already covered by [3].

2 Scientific Aspects of the NUbot Humanoid Robot System and Research Interests of the Lab and Team

The scientific aspects of the current NUbot system involve deep learning on robots, software engineering for robotics and AI, as well as various aspects of computer vision, localisation, human-robot interaction and machine learning.

2.1 Current Research Projects in the Newcastle Robotics Lab

The following paragraphs briefly describe some of the NUbots' current projects, where more details on the NUbots research in the past 15 years can be found, e.g., in [3] and the relevant webpages, e.g., at `www.robots.newcastle.edu.au`.

Deep Learning in Robotics: Deep learning has become a central topic of research in the lab. Several PhD and undergraduate projects involve deep learning. Tensorflow and Caffe have been integrated into the NUbots' system and trialled for the tasks of face and pedestrian detection. On the topic of deep learning there are two recent publications. They address the topics of scene sentiment analysis where several deep networks were combined into a larger system [1], and the use of synthetic data generated by computer graphics techniques for training deep nets on object detection tasks [10].

Software Engineering for Robotics: Much work has been focused on the underlying software architecture and external utilities to enable flexibility and extensibility for future research [11, 8]. Projects undertaken include improving the configurability of the software system via real-time configuration updates, development of a web-based online visualisation and debugging utility [4] and the application of software architectural principles to create a multi-threaded event-based system with almost no run-time overhead. Some of this work is still in progress.

Manifold Learning and Alignment: In several past projects we investigated non-linear dimensionality reduction methods in order to achieve more accurate processing of high-dimensional motion, visual and acoustic data. Manifold alignment is part of an on-going PhD project using simulated data [5]. Another new research topic is the use of persistent homology for data analysis [14].

Robot Vision: Several topics have been investigated including object recognition, horizon determination, edge detection, model fitting and colour classification using ellipse fitting, convex optimisation and kernel machines. Recent work has resulted in a fully-autonomous method of colour look-up table adaptation for changing lighting conditions, allowing us to overcome one of the major limitations of the colour look-up table system. Recent publications are available e.g. from [9, 13].

Localisation: Motivated reinforcement learning was employed to optimise head movement behaviour, allowing a robot to learn to choose landmarks to localise efficiently during a soccer game [7]. Visual SLAM point-clouds based on Semidirect Visual Odometry (SVO) [6] are also being enhanced with semantically labelled objects which will allow for merging with map priors of the soccer field.

2.2 Background and Research Interests of the NUbots Team Members

- *Matthew Amos* is a fifth year undergraduate student studying a combined degree in Computer Science and Computer Engineering. He is interested in computer vision and machine learning.
- *Alex Biddulph* is studying for a Doctorate of Philosophy in Computer Engineering. Alex has undergraduate degrees in Computer Engineering and Computer Science with Honours in Computer Engineering. The focus of Alex's studies will revolve around the symbiotic relationship between hardware and algorithms, with a focus on computer vision.
- *Associate Professor Stephan Chalup* is the head of the Newcastle Robotics Lab. His current research focuses on deep learning, neural information processing systems and topological data analysis.
- *Luke Farrawell* is a recent Software Engineering (Honours) graduate and research collaborator. His interests include robotics, computer graphics and virtual reality. He contributes to NUsight; the real-time web based debugging environment.
- *Daniel Ginn* is pursuing a PhD in Computer Science with focus on questions of localisation and mapping using robotic platforms in the context of RoboCup. 2017 was the first time he joined the NUbots competition team.
- *Trent Houliston* is completing his PhD in software engineering focusing on software architecture for robotics and real-time computer vision. He has been a part of NUbots since 2013 and was NUbots team leader in 2016 and 2017.
- *Dr. Alexandre Mendes* is deputy head of the Newcastle Robotics Lab. He is a Senior Lecturer in Computing and Information Technology. He joined the group in September 2011 and his research areas are evolutionary algorithms and optimisation.
- *Josephus Paye* is a second year undergraduate student studying Computer Science, with a major in Computer Systems and Robotics. He contributes to NUsight, the web-based debugging environment.
- *Peter Turner* is technical staff in the School of Electrical Engineering and Computer Science. Peter provides hardware support and assists the team with physical robot design upgrades.
- *Taylor Young* is a third year undergraduate student studying Electrical Engineering. He contributes the hardware based aspects, the design and manufacturing of the robots.

The current NUbot team acknowledges the input of team members of previous years and other colleagues from the Newcastle Robotics Lab. Details are linked to `www.robots.newcastle.edu.au`.

2.3 Related Research Concentrations

The *Interdisciplinary Machine Learning Research Group (IMLRG)* investigates different aspects of machine learning and data mining in theory, experiments

and applications. The IMLRG's research areas include: Dimensionality reduction, vision processing, robotics control and learning, evolutionary computation, optimisation, reinforcement learning, kernel methods, and deep learning.

3 History of the NUbots and Prior Performance in RoboCup Competitions [3]

The NUbots team, from the University of Newcastle, Australia, competed in the Four-Legged-League from 2002-2007 using Sony AIBO ERS-210 and ERS-7 robots. The NUbots participated for the first time at RoboCup 2002 in Fukuoka in the Sony Four-Legged League (3rd place). At RoboCup 2006 in Bremen, Germany, the NUbots won the title.

From 2008 to 2011 they used the Aldebaran Nao within the Standard Platform League. They achieved a first place in 2008 as part of the NUManoid team in Suzhou, China.

The NUbots joined the Kidsize Humanoid League in 2012 with the DARwIn-OP robots, and ported their SPL codebase to the new platform. The NUbots retained a robust and fast vision and localisation system from the SPL, and ported the B-human NAO walk to the DARwIn-OP for 2012-2013. From 2014-2016 the NUbots redeveloped their software system based on the NUClear software architecture [9]. For the Darwins they made small modifications of the head, feet and cameras. 2017 was the first year where an Igus platform based robot was added to the NUbot kidsize team that then comprise a mixed team of DARwIn and Igus-Nimbro based robots. Due to the league's hight restrictions the top of the Igus-Nimbro robot's skull had to be cut off. In 2017 the NUbots reached the quaterfinals in the Kidsize Humanoid League. After the competition all DARwIn-OP robots of the team retired. In 2018 the NUbots compete in the teen-size humanoid league using their NUgus robots that are based on the Igus-Nimbro design [2].

4 Software and Hardware Overview

The NUbots team's software source is available from [12] and is covered under the GPL. This code includes associated toolkits for building and deploying the software. Our software is designed to work on multiple robotic platforms, and all of the individual modules have been designed to be easily used in other systems. The flexibility of our approach has been demonstrated in a deployment of the NUbots vision system on a marine platform[1]. The NUbots code-base is currently being ported to a larger humanoid platform, the Igus. Significant work has gone in to ensuring that the codebase and associated dependencies can be easily cross-compiled on to both 32-bit and 64-bit platforms, allowing for our codebase to

[1] http://www.newcastle.edu.au/about-uon/governance-and-leadership/faculties-and-schools/faculty-of-engineering-and-built-environment/maritime-robotx-challenge-team/about-us

be easily ported between different architectures. Further work has been put into extending architecture support to arm-based platforms.

Following development of a new software system in 2014-2017, the NUbots are now focusing on the RoboCup Teen-size League. Their research aims include efficient vision processing; improved localisation; generic ball detection; and improving the walk engine. The NUClear based NUbot software is designed to allow new teams and team members to easily understand and innovate on existing code, and is made freely available to encourage research and innovation.

5 Enhancements of the NUbots hardware and software compared to the previous year

The NUbots team have built a team of teen sized robots, based of the Igus-Nimbro, making significant changes in the design of the platform. Some of these changes aid in an alternative manufacturing process used. A carbon fiber embedded nylon with continuous carbon fiber reinforcing is used as the main structural material in the manufacturing. Designed in a CAD program and 3D printed allowing for easy design modifications. Within this larger platform better computing power can be taken advantage of, with a Intel NUC7i7BNH being a major improvement over the Darwin-OP fit-PC2i. An upgraded vision system consisting of two Point Grey Flea3 USB3Vision cameras with large field of view equidistant spherical lenses is used. A new deep learning vision algorithm has been developed. An improved cooling solution is also being implemented to ensure that the CPU and servos remain cool.

5.1 Details on software and hardware used from other teams

Acknowledgement of use of code for the walk engine The NUbots DARwIn-OP robots used a walk engine based on the 2013 Team Darwin code release. We acknowledge the source of this code. The NUbots have ported this code to C++ and restructured the logic, making numerous structural and technical changes. The current code for the NUgus robot walk is a further modification and extension of the code that the NUbots used on their Darwins in previous years.

Acknowledgement of other software used from other teams The NUbots NUgus robots are based on the 2016 Team Nimbro design files. We acknowledge the source of this design. The NUbots have have made modifications to the design to account for a different printing process and to improve the usability of the design. The modified design files are released under the original license [15].

The NUbot teams own contributions The NUbots vision system now utilises an efficient and intelligent image subsampling algorithm. This subsampling technique allows for fast, efficient, and accurate deep learning to be performed on high resolution images at frame rates in excess of 100 frames per

second. The implemented algorithm provides guarantees over the number of sampled pixels within objects of certain sizes, allowing the user full control over the trade-off between the algorithms run time and accuracy.

The improved cooling system places extra fans and vents at strategic points around the robot to increase airflow in and around the CPU and servos of the robot.

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References

1. Asad Abbas and Stephan K. Chalup. Group emotion recognition in the wild by combining deep neural networks for facial expression classification and scene-context analysis. In *Proceedings of the 19th ACM International Conference on Multimodal Interaction*, ICMI 2017, pages 561–568, New York, NY, USA, 2017. ACM.
2. Philipp Allgeuer, Hafez Farazi, Grzegorz Ficht, Michael Schreiber, and Sve Behnke. The igus humanoid open platform: A child-sized 3d printed open-source robot for research. *German Journal on Artificial Intelligence (KI)*, 30:315–319, 2016.
3. Matthew Amos, Alex Biddulph, Stephan Chalup, Luke Farrawell, Jake Fountain, Daniel Ginn, Trent Houliston, Robert King, Alexandre Mendes, Peter Turner, and Josiah Walker. The NUbots team description paper 2017. In *The official website of the RoboCup Humanoid League*, 2017.
4. Brendan Annable, David Budden, and Alexandre Mendes. Nubugger: A visual real-time robot debugging system. In *RoboCup 2013: Robot Soccer World Cup XVII*, Lecture Notes in Artificial Intelligence (LNAI). Springer, 2014.
5. Fayeem Aziz, Aaron S.W. Wong, James Welsh, and Stephan K. Chalup. Performance comparison of manifold alignment methods applied to pendulum dynamics. In *Applied Informatics and Technology Innovation Conference (AITIC)*. Springer, 2016. accepted 1 September 2016.
6. Christian Forster, Zichao Zhang, Michael Gassner, Manuel Werlberger, and Davide Scaramuzza. Svo: Semidirect visual odometry for monocular and multicamera systems. *IEEE Transactions on Robotics*, 33(2):249–265, 2017.
7. Jake Fountain, Josiah Walker, David Budden, Alexandre Mendes, and Stephan K. Chalup. Motivated reinforcement learning for improved head actuation of humanoid robots. In *RoboCup 2013: Robot World Cup XVII*, volume 8371 of *Lecture Notes in Artificial Intelligence (LNAI)*, pages 268–279. Springer, 2014.
8. Trent Houliston, Jake Fountain, Yuqing Lin, Alexandre Mendes, Mitchell Metcalfe, Josiah Walker, and Stephan K. Chalup. Nuclear: A loosely coupled software architecture for humanoid robot systems. *Frontiers in Robotics and AI*, 3(20), 2016.

9. Trent Houliston, Mitchell Metcalfe, and Stephan K. Chalup. A fast method for adapting lookup tables applied to changes in lighting colour. In *RoboCup 2015: Robot World Cup XIX*, volume 9513 of *Lecture Notes in Artificial Intelligence (LNAI)*, pages 190–201. Springer, 2015.
10. Abdul Jabbar, Luke Farrawell, Jake Fountain, and Stephan K. Chalup. Training deep neural networks for detecting drinking glasses using synthetic images. In Derong Liu, Shengli Xie, Yuanqing Li, Dongbin Zhao, and El-Sayed M. El-Alfy, editors, *Neural Information Processing: 24th International Conference, ICONIP 2017, Guangzhou, China, November 14-18, 2017, Proceedings, Part II*, pages 354–363, Cham, 2017. Springer International Publishing.
11. Jason Kulk and James Welsh. A nuplatform for software on articulated mobile robots. In *1st International ISoLA Workshop on Software Aspects of Robotic Systems*, 2011.
12. M. Metcalfe, J. Fountain, A. Sugo, T. Houliston, A. Buddulph, A. Dabson, T. Johnson, J. Johnson, B. Annable, , S. Nicklin, S. Fenn, D. Budden, J. Walker, and J. Reitveld. Nubots robocup code repository. https://github.com/nubots/NUbots, January 2018.
13. Mitchell Metcalfe, Brendan Annable, Monica Olejniczak, and Stephan K. Chalup. A study on detecting three-dimensional balls using boosted classifiers. In *Interactive Entertainment 2016, at the Australasian Computer Science Week (ACSW 2016), Canberra, Australia, 2-5 February, 2016*. ACM Digital Library, 2016.
14. Rahul Paul and Stephan K. Chalup. A study on validating non-linear dimensionality reduction using persistent homology. *Pattern Recognition Letters*, 100:160–166, 2017.
15. T. Young and A. Buddulph. Nubots hardware repository. https://github.com/nubots/NUware, January 2018.