The NUbots' Team Description for 2004

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Abstract. The NUbots are a competitive robot soccer team specialised in the Sony Four-Legged League of RoboCup using the current AIBO ERS-7 robots. The present paper describes the team, and how its strategy and approach evolved between RoboCup 2002 and the most recent competition, the Australian Open in April 2004. The paper also addresses associated research projects and relevant aspects of the study and research environment of the NUbots' host institution, the University of Newcastle in Australia.

1 Introduction

One of the central aims of current robotics research is to develop and program robots that can support humans with routine as well as dangerous or expert tasks. Our mission is to contribute to a responsible development and application of robotics. Future robots should help people and improve safety and quality of our life and environment.

The NUbots are the University of Newcastle's RoboCup team. They were founded in 2002 in the first instance to become a high performance competitive robot soccer team at RoboCup. Although the NUbot competition team is the most well-known section of the Newcastle Robotics Laboratory there are other research focused projects associated with the laboratory. They address topics which integrate the areas control, machine learning, and statistics in robotics applications.

Education of postgraduate and undergraduate students in the Newcastle Robotics Lab addresses general methods of software engineering, systems design, agent technologies and project management as well as robotics specific skills such as computer vision methods, experimental evaluation, and algorithms for optimisation and control.

2 History of Achievements in Previous Competitions

The University of Newcastle's RoboCup initiative started in 2001. After the introduction of new robotics and machine learning related courses and projects two undergraduate students participated in RoboCup Junior in Seattle and won the world title. After their return the NUbot team was founded which from then on participated in the following competitions of the Sony Four-Legged League:

- *Australian Open Competition 2002 in Newcastle:* This was the first competition for the newly founded and unexperienced NUbot team. It was defeated by the University of New South Wales team 13-0, and the University of Melbourne team 6-0. Finally the University of Melbourne beat the NUBots 4-3 in a penalty shootout.
- *RoboCup 2002 in Fukuoka, Japan:* The new NUbot team entered the Sony Four-Legged League and instantly achieved a third place.
- *Australian Open Competition 2003 in Sydney:* In a dramatic match the NUbots played 3-5 against the team of UNSW/NICTA and became second before the teams of UTS and Griffiths University.
- *RoboCup 2003 in Padova, Italy:* The 2003 NUbot team achieved third place in RoboCup 2003. It was only beaten in the semi finals by the team of the University of Pennsylvania 3-4 on penalties. The playoff for third place saw the NUbots beat last year's world champions Carnegie Mellon 4-1. The NUbots achieved the most goals for (83), and fewest goals against (3). It was noticed that they matched the previous record for the highest score in a legged league game at RoboCup by winning a match 16-0 against one of the other competitors.
- *Australian Open Competition 2004 in Sydney:* In the 2004 Australian Open Competition the NUbots achieved a second place and defeated the reign world champion rUNSWift. All teams except the winning team had recently switched to the new ERS-7 robots and the Australian Open was a first test of their new hardware in a competitive game situation.

3 Background of the NUbots' Team Members

The NUbot team for RoboCup 2004 consists of four students and three academics. The main part of the software development is done by the student team:

- *Mr. Lee Andy Yung Li* is studying for the Bachelor of Electrical Engineering. He recently joined the NUbots as support developer for the NUbots' 2004 software system.
- *Mr. Timothy Moore* recently commenced a Masters by Research course and investigates the application of Bayesian Statistics in robotics. Tim will participate in RoboCup as NUbot developer, specialised on vision and localisation, for the first time 2004.
- *Mr. Craig Murch* is Honours student in Computer Science and research assistant in the Newcastle Robotics Laboratory. His research area is advanced machine learning and robotics. He is one of the main developers of the NUbots since 2002.
- *Mr. Michael Quinlan* is Ph.D. student in computer science and software engineering and research assistant in the Newcastle Robotics Laboratory. He

is the leading developer in the student team and member of the NUbots since 2002. In his research Michael investigates applications and implementations of machine learning methods in the Sony four-legged league.

All student developers are full-time students in the School of Electrical Engineering & Computer Science at the University of Newcastle. Three academic team members provide guidance and research supervision:

– *Dr. Stephan Chalup* is lecturer in computer science and software engineering at the University of Newcastle. He is one of the initiators of the University of Newcastle's RoboCup activities since 2001. His background is machine learning, mathematics and neurobiology. He has published in the areas of machine learning, neural networks, and robotics. He is supervisor of several research students and coordinator of the Interdisciplinary Machine Learning Research Group (IMLRG). Stephan Chalup is member of the ARC Research Network in Robotics (`http://www.robotics.edu.au`).
– *Dr. Robert King* is a lecturer in statistics at the University of Newcastle with particular interests in flexibly-shaped distributions, statistical computing and Bayesian knowledge updating. He joined the NUbots in 2004.
– *Prof. Dr. Rick Middleton* is member of the NUbots since RoboCup 2002. He has published research results in a range of areas including electric machine control, adaptive control, robot control, digital control systems theory using delta operators, multirate and sampled-data systems, performance limitations in feedback control systems (including multivariable and nonlinear systems), metal rolling control problems, robotics. He is co-author of the text "Digital Control and Estimation: A Unified Approach" (Prentice-Hall). He has been involved in industrial applications of systems and control to radio astronomy, satellite tracking, metals processing industries, power electronic inverter controls and various applications of Kalman filtering. He has served as an associate editor of both the IEEE Transactions on Automatic Control and the IEEE Transaction on Control System Technology. He is an Associate Editor of Automatica and is Director of the ARC Centre for Complex Dynamic Systems and Control (CDSC) at the University of Newcastle.

Ex-members of the NUbots' 2002 student team are Leonie Freeston, Nathan Lovell, Joshua Marshall, and support team members Nathan Creek and Drew Mellor. Ex-NUbots of the 2003 team are Michaela Freeston, Christopher Seysener, and support team members Oliver Coleman, Jared Bunting and Will McMahan.

4 Research in the Newcastle Robotics Laboratory

The following subsections provide brief summaries of some current research projects in the Newcastle Robotics Laboratory as well as links to corresponding publications.

4.1 Robot Vision

Vision is one of the major research areas associated with the NUbot team. Several subtopics have been investigated including object recognition, horizon determination, edge detection, and colour classification using ellipse fitting, convex optimization and kernel machines. Publications are available e.g. from [1, 3, 4, 9, 12, 13, 15, 16].

4.2 Localisation and Kalman Filters

Research on the topic of localisation focused on Bayesian approaches to robot localisation including Extended Kalman Filters and particle filter based methods. We are particularly interested in further modifications of the Kalman Filter to handle non-ideal information from vision or alternative Bayesian methods with non-Gaussian errors. For information about our current approach see [1, 3, 6, 7].

4.3 Navigation and Obstacle Avoidance

The suitability of different path planning and obstacle avoidance techniques is compared in simulated environments to real-world environments on the task of the RoboCup Legged League 2003 Obstacle Avoidance Challenge. We investigate how the perceptions of the agents in the simulated environment and real-world environment impact on the choice of obstacle avoidance and path planning methods used for the task [5].

4.4 Legged Robot Locomotion

We analysed existing gaits of the AIBO robots and included low level controller parameters in the NUbots' locomotion engine. The task of gait optimisation involves learning in a poorly structured high dimensional parameter space. For this purpose we developed and tested different optimization schemes based on evolutionary computation [12]. The outcome of the training experiments was one of the fastest walks for the Sony AIBO ERS-210a [4, 10, 12]. Current work investigates how to find a suitable gait for the new ERS-7 robots when used in the four-legged league.

Another project is about the application of spiking neural networks to robot locomotion control with particular focus on bi-ped locomotion.

4.5 Traction Monitoring

Methods to monitor traction measures are developed and employed for collision detection, to increase the speed of the robots, and to find a good strategy to deal with situations where the legs of two robots get entangled (*leg-lock*) [11]. The techniques used are examples of applications of fault detection ideas, which may further find use in monitoring other collisions and unusual situations.

4.6 Experimental Design

We are interested in applying the principles of experimental design to the assessment of algorithms. Simulated robots and Sony AIBO robots are used to evaluate machine learning methods specifically designed for robot learning.

5 Aspects of the NUbots' Software System

The NUbots' software system evolved from its first version designed for RoboCup 2002, through a revised and updated system for RoboCup 2003, to the latest implementation used at the Australian Open 2004.

Technical details about software and concepts employed by the 2002 and 2003 NUbot teams are available in the NUbots' 2002 and 2003 team reports and team description papers [1–3].

The NUbots' software system at RoboCup 2003 was a substantially revised and extended version of the 2002 system. Further changes for the 2004 system were primarily driven by the introduction of new rules and the new ERS-7 robots.

5.1 Summary of Changes of the System for the Australian Open Competition 2004

For the 2004 competitions several rule changes as well as the new ERS-7 robot were introduced. For the Australian teams the Australian Open Championships in Sydney were a first test of playing under the new rules and with the new robot hardware in a competition.

Removal of the Center Beacons. One of the rule changes for RoboCup 2004 is the removal of the two center beacons. The NUbots' implementation of localisation did not rely on any particular landmarks, so existing code works with a minor deterioration in performance.

Changes in Lighting Conditions. At the Australian Open the lighting conditions were very good and similar to 2003. However, the new rules allow that light intensity can be reduced to 500 *lux*. This could have major impact on the play of the four-legged teams in Lisbon.

The New ERS-7 Robot and What Differences it Makes. The ERS-7 differs in many key aspects from the ERS-210 series robots.

The camera has increased in resolution from 176×144 pixels to 208×160 pixels and the frame rate raised from 25 to 30 frames per second. However, the camera on the ERS-7 appears to result in much darker images and some early studies [14] have indicated that the camera may be of a lower quality which leads to a blue tint around the edge of the image.

The ERS-7 robots appear much stronger and faster than the ERS-210 robots. After a short amount of time the ERS-7s learnt to walk forwards approximately 40% faster. Although this is a great improvement it does present some new problems. The increase in frame rate is much less than the increase in walking speed, meaning more movement can occur between vision frames. In the past we were able to move at full speed and still maintain control of a ball, but it is unclear if this will be the case with the new robots.

Another significant physical change to the robot has been to the head. Sony has removed the roll motor and added a second tilt motor. The head is also longer and of a more rounded shape. The dimensions of the head and the ability to move it differently require the complete re-development of code involving the head.

Although the ERS-7 seems to be an improvement over the previous model it is still unclear if in 2004 these changes will be enough to beat ERS-210s which have had several years of fine tuning.

5.2 Overview of the Main Components of the NUbots' Software System

The main modules address vision, localisation, locomotion, and behaviour. The following subsections briefly summarise the corresponding system components. Their 2002/2003 versions were described in [1, 3, 9, 15].

Vision The design of the vision system included an analysis of the camera's characteristics, including a response analysis and an image deviation/noise level analysis [1, 3, 9, 15]. Image processing was performed in four steps:

- Colour Classification
- Run Length Encoding
- Blob Formation
- Object Recognition

Some of the major new features in the vision system for 2003 included [15, 16]:

- Field and Sideline Detection
- Penalty Box Corner Detection
- Centre Circle Detection
- Centre Corner Point Detection
- Ellipse and Circle Fitting to the Ball
- Infrared Distance Detection
- Ball on Wall Detection

Localisation The NUbots' system of localisation and world modelling [6, 7] is based on an Extended Kalman Filter (EKF). An integrated, 5th order model for the robots own location and the ball location is used.

The 2003 code included sensing of the perceived angle between two objects; rather than treating each object in a vision frame independently. We also improved the mechanism for constraining the robot's localisation estimate to the field of play to include the area around the goal mouth. Previously, this area was implicitly excluded as being beyond the 'goal line'.

The system includes an algorithm for dealing with both the lost robot problem, (or the 'kidnapped robot problem') and measurement outliers (or spurious measurements). We note that the lost robot problem is a modern form of a long studied problem in detecting and tracking jumps in an estimation setting.

The method recognises several successive (or almost successive) bad (i.e conflicting with the current model) vision measurements to distinct object types. By choosing appropriate threshold values for various constants (such as how many distinct object types had to be seen, how bad the measurements had to be, etc.), the robot is able to detect that it has been manually picked up and moved almost without fail. Also, where bad measurements were on a single object type, this was rejected as an outlier and not used in the model (for example if a beacon is removed and deliberately misplaced on the field). As well as detecting manual robot repositioning, the detection system allows the robot to quickly regain its bearings after receiving large amounts of erroneous odometry data (as in a severe collision with another robot).

Locomotion The NUbots' 2002 and 2003 locomotion engine was initially inspired by the concept of parameterised walk (Pwalk) [8]. However, during development is was completely redesigned. In depth empirical testing of different parameter configurations and relations which were obtained via inverse kinematics improved the walking, turning, and chasing speed of the robots and the effectiveness of their kicks.

The NUbots' kicking system allows for quicker kick development and more flexible kick execution. Kicks are loaded from a file (rather than compiled into code like many teams), and this file can be reloaded at any time. This allows new kicks to be developed extremely rapidly. Interpolation was added in order to better tweak the speed of different parts of a kick motion. Interpolation was also added between certain motion transitions in order to make the robot move more naturally.

Behaviour High level behaviour is responsible for the overall team strategy. It is concerned with matters such as deciding where the robot should move to, and if/when the robot should be chasing the ball. With the introduction of wireless communication, high level behaviour has also become responsible for coordinating the actions of multiple robots in an efficient manner.

A central policy of the current behaviour system is that the closest robot to the ball will attack it. Each robot sends its perceived distance to the ball over the wireless network. Other robots will move to an area on the field determined by the captain. It is possible to change which player acts as captain at run-time, but the goalkeeper is typically assigned the captain role. There is no explicit negotiation taking place. Since all the robots are equally capable of determining which robot is the optimal chaser, there is no need for an explicit decision making process to take place over the wireless network. Robots not currently chasing will look for the ball in the direction indicated by their shared world model. They will also move around within their assigned position area based on the position of the ball in order to maximise their chance of gaining possession.

6 Related Research Concentrations

The *ARC Centre for Complex Dynamic Systems and Control (CDSC)* is linked to the School of Electrical Engineering and Computer Science at the University of Newcastle, Australia. The Centre provides significant industrial and manufacturing performance advances by working on approaches to control and scheduling. These approaches aim to unify the use of disparate technologies, namely, mathematical modelling through to computer systems, electromechanical machinery, scheduling systems and chemical processing. This will bring about an increase in the performance of industry in key areas including product quality, plant efficiency, safety, productivity, waste minimisation, pollution control and operational flexibility. For more details see `http://www.ee.newcastle.edu.au/cdsc/`

The *Interdisciplinary Machine Learning Research Group (IMLRG)* a research group in the Discipline of Computer Science and Software Engineering at the University of Newcastle. It investigates different aspects of machine learning and data mining in theory, experiments and applications. Particular emphasis is put on interdisciplinary projects. The IMLRG's research areas include: Data mining, machine learning, robotics, control and learning, neuroscience, bioinformatics, evolutionary computation, reinforcement learning, and statistical learning. For more details see `http://www.cs.newcastle.edu.au/Research/IMLRG/`

7 Robotics Education at the University of Newcastle

The School of Electrical Engineering & Computer Science offers a range of undergraduate courses which are an excellent preparation for postgraduate research studies in the area of robotics. Of particular interest are the following courses:

- *Comp3330 Machine Intelligence* is a 3rd year elective course which provides an overview of topics at the intersection of Artificial Intelligence and Machine Learning.
- *Comp4110 Advanced Machine Learning* approaches topics from the areas of machine learning, data mining, neuroinformatics, and robotics. The course includes an introduction to research techniques and literature/library tools.
- *Seng4160 Advanced Robotics* uses as primary platform Sony AIBO robots.
- *Elec2120 Sensors and Actuators* combines a theoretical background with practical experience of sensors, actuators and electronic transducers commonly used in measurement and control of modern industrial plants.

- *Elec3710 Microprocessor Systems* involves learning assembly language programming on the Intel 80x86 architecture, 'C' language programming for embedded applications, handling interrupt driven I/O, the fundamentals of real time operating systems, and interfacing to I/O devices.
- *Elec3850 Introduction to Electrical Engineering Design* includes some or all of: Electrical, electronic, communications, computing, software, signal processing, control, and mechanical systems.
- *Elec4700 Advanced Computer Systems* introduces students to advanced concepts in computer architecture and design emphasizing quantitative methods for performance evaluation.

This is only a small selection of courses relevant to robotics. More details about the undergraduate programme can be obtained form the following page
`http://www.eng.newcastle.edu.au/eecs/current/courses.html`
Information about Masters and PhD studies at the University of Newcastle are available from the "Research Higher Degree Candidate's Guide":
`http://www.newcastle.edu.au/research/rhd/guide/contents.html`
Information about funding and scholarships can be obtained from
`http://www.newcastle.edu.au/research/rhd/guide/schols.html`.
For enquiries about local scholarships or exchange arrangements please contact the school's office: School of Electrical Engineering and Computer Science, Faculty of Engineering and the Built Environment, The University of Newcastle NSW 2308, Australia Phone: +61 2 492 15330, Fax: +61 2 492 16929, URL: `http://www.eecs.newcastle.edu.au/` or contact directly Dr. Stephan Chalup (email: `chalup@cs.newcastle.edu.au`) or Professor Richard Middleton (email: `rick@ee.newcastle.edu.au`).

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Links to the NUbots' publications can be found at the NUbots' webpage

`http://robots.newcastle.edu.au/`

References

1. Jared Bunting, Stephan Chalup, Michaela Freeston, Will McMahan, Rick Middleton, Craig Murch, Michael Quinlan, Christopher Seysener, and Graham Shanks (2003). *Return of the NUbots ! The 2003 NUbots Team Report.*

2. Stephan K. Chalup, Oliver J. Coleman, Michaela N. Freeston, Richard H. Middleton, Craig L. Murch, Michael J. Quinlan, Christopher J. Seysener, and Graham D. Shanks (2003). The NUbots Team Description for 2003. *RoboCup 2003 Symposium.*

3. Chalup, S., Creek, N., Freeston, L., Lovell, N., Marshall, J., Middleton, R., Murch, C., Quinlan, M., Shanks, G., Stanton, C., and Williams, M.-A. (2002). *When NUbots Attack ! The 2002 NUbots Team Report.* School of Electrical Engineering & Computer Science Technical Report, The University of Newcastle, Australia.

4. Stephan K. Chalup and Craig L. Murch (2004). Machine Learning in the Four-Legged League. *3rd IFAC Symposium on Mechatronic Systems*, accepted.

5. Oliver J. Coleman and Stephan K. Chalup (2003). Towards Matching Perception in Simulated and Real World Robot Navigation. *Australian Conference on Artificial Life (ACAL'2003).*

6. Leonie Freeston (2002). *Localization and World Modelling.* `http://murray.newcastle.edu.au/users/students/2002/c9806118/main.html`

7. Michaela Freeston (2003). *Localisation and World Modelling in Robot Soccer.* School of Electrical Engineering and Computer Science, The University of Newcastle, `http://murray.newcastle.edu.au/users/students/2003/c2003066/`

8. Hengst, B., Phan, S.B., Ibbotson, D., and Sammut, C. (2002). Omnidirectional Locomotion for Quadruped Robots. *RoboCup 2001: Robot Soccer World Cup V*, pp.368–373.

9. McMahan, W. and Bunting, J. (2002). *Vision Processing.* `http://murray.newcastle.edu.au/users/students/2002/c3012299/`

10. Nate Kohl and Peter Stone (2004). Machine Learning for Fast Quadrupedal Locomotion. *The Nineteenth National Conference on Artificial Intelligence*, AAAI 2004, to appear.

11. Quinlan, M., Murch, C., Middleton, R., and Chalup, S. (2003). Traction Monitoring for Collision Detection with Legged Robots. *RoboCup 2003 Symposium* (received engineering paper award).

12. Quinlan, M.J., Chalup, S.K., and Middleton, R.H. (2003). Techniques for Improving Vision and Locomotion on the Sony AIBO Robot. *Proceedings of the 2003 Australasian Conference on Robotics & Automation (ACRA'2003).*

13. Quinlan, M.J., Chalup, S.K., and Middleton, R.H. (2003). Application of SVMs for Colour Classification and Collision Detection with AIBO Robots. *Advances in Neural Information Processing Systems (NIPS'2003).*

14. `http://www.informatik.uni-bremen.de/~roefer/ers7/`, viewed on 30.4.2004.

15. Seysener, C. (2003). *Vision Processing for RoboCup 2003/2004.* School of Electrical Engineering and Computer Science, The University of Newcastle, `http://murray.newcastle.edu.au/users/students/2003/c9807674/index.html`

16. Seysener, C., Murch, C., Middleton, R. (2004). Extensions to Object Recognition in the Four-Legged League. *RoboCup 2004 Symposium.*