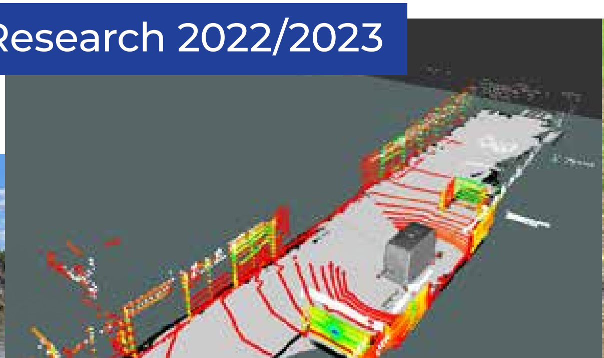
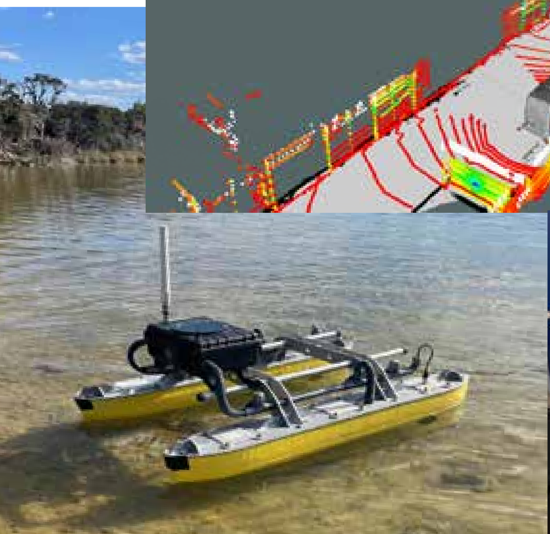
THE UNIVERSITY OF WESTERN AUSTRALIA

School of **Engineering**

Computational Intelligence Information Processing Systems

Research 2022/2023





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Foreword

from the Head of CIIPS

We are celebrating the 25th anniversary of the Robotics and Automation Lab together with the 15th anniversary of the Renewable Energy Vehicle Project (REV) at UWA. REV started with converting a Hyundai Getz and later a Lotus Elise to electric drive at a time when commercial electric vehicles were not yet available. This, of course, has changed and we now finally see the ramping up of EV sales in most countries. Our research work has therefore concentrated on autonomous vehicles. After implementing an advanced driver assistance system for a BMW X5, we built Australia's first fully autonomous Formula-SAE race car and are now concentrating our work on two autonomous shuttle buses, for which we have implemented a complete software stack plus some additional sensors and hardware. After two years of regular autonomous drives on the UWA campus, we are now looking at setting up our first trial on a public road in Perth's northern suburb of Eglinton.

Simulation systems remain an important sector of our work. We simulate all shuttle bus software on our digital model of the UWA campus using the Carla system. For robotics research and education, we use our own EyeSim system, which we make available as free software to all interested users.

As in the previous years, it is great to have several local start-up companies as cooperation partners, especially Stealth Technologies, Electro.Aero/Electro.Nautic, and EV Works. It is good to see these companies progressing, as it is especially hard for them in the current economic climate.

The year 2022 was also a turning point in UWA's educational program. The new Vice-Chancellor brought back the standard four-year Bachelor's degree and we were able to create a new Major in 'Automation and Robotics' within the Bachelor of Engineering degree. This new Major has been extremely successful from the start, attracting the second highest number of students of all Engineering Majors.

Professor Thomas Bräunl
Head CIIPS
Computational Intelligence—
Information Processing Systems

Introduction to CIIPS

The Computational Intelligence–Information Processing Systems Group (CIIPS) has evolved from the Centre for Intelligent Information Processing Systems which was established in November 1991 as a 'Category A' Centre within the then Department of Electrical and Electronic Engineering at The University of Western Australia. Formerly existing as the Digital Signal Processing Research Group within the Department, it developed into a multidisciplinary research centre bringing together researchers from engineering, science, mathematics and medicine.

Activities

The group combines an active teaching program with pure and applied research to provide an environment in which innovative theoretical developments can be rapidly turned into technologies that provide solutions to a range of real-world problems.

The group is active in the areas of artificial neural networks, embedded systems, digital signal processing, image processing, mobile robots, parallel and reconfigurable computing, pattern recognition, electromobility and automotive systems.

Strong and successful collaboration between the group and industry is a key element in its operation. Joint research and development projects with a number of Australian companies have been undertaken, as well as contract research for industry, government and other bodies.

Baxter being trained by students to perform a task

Equipment

In the **REV Automotive Lab**, the group operates as research vehicles—

- 2 x Ligier Shuttle Buses (Autonomous Driving)
- BMW X5 (Advanced Driver Assistance Systems)
- Hyundai Getz (Electric conversion, road-registered)
- Lotus Elise S2 (Electric conversion, road-registered)
- Driverless Electric Formula-SAE Race Car
- Electric Jet-Ski (boat-registered)
- Electric Hydrofoil (boat-registered)
- Electric Scooter

In the **Robotics and Automation Lab**, the group operates numerous autonomous mobile robot systems, including about 50 driving robots, three autonomous underwater vehicles, five walking robots and two drones.

- 5 x Pioneer AT mobile outdoor robots
- 3 x UR5 robot manipulators (5kg payload)
- Nachi robot manipulator (150kg payload)
- Festo automation production line
- Numerous own mobile robot developments

Contact Details

Computational Intelligence—Information Processing Systems (CIIPS)
Department of Electrical, Electronic and Computer Engineering
School of Engineering
The University of Western Australia, M018
Crawley, Perth, WA 6009 AUSTRALIA
Email: rob@roblab.org
Phone: +61 (8) 6488 1763
Website: robotics.ee.uwa.edu.au

Members of CIIPS

Academic

Professor Thomas Bräunl
(Head of CIIPS)
Dipl.-Inform., MS, PhD, Habil., SMIEEE
Electromobility; Automotive Systems; Robotics; Image Processing; Concurrency; Embedded Systems
thomas.braunl@uwa.edu.au

Adjunct Professor David Harries
BSc, DipEd, MEnvStud, PhD
Smart Grids; Renewable Energy;
dnharries@gmail.com

Adjunct Senior Research Fellow
Dr Robert Reid
Mobile Robots

Adjunct Research Fellow
Dr Kai Li Lim
EV Charging Systems and Autonomous Navigation

Adjunct Research Fellow
Marcus Pham
Embedded Systems

Professional

Ivan Neubronner
Senior Technician

Linda Barbour
Graphic Designer

PhD

Pierre-Louis Constant
Autonomous Marine Vessels

Thomas Drage
Autonomous Driving

Michael Finn
Artificial Life

Xiangrui Kong
Visual Navigation

Zhihui (Eric) Lai
End-to-End AI Methods in Autonomous Driving

Elliot Nicholls
Automation in Agricultural Systems

Kieran Quirke-Brown
Automated Obstacle Avoidance

Machiel van der Stelt
Road Safety

Masters by Research

Kyle Carvalho
Autonomous Vehicle Control using Global Navigation Satellite Systems

Yuchen Du
Lidar-based Autonomous Driving

Bachelor of Philosophy

Jai Castle
Autonomous Shuttle Bus

Edward Yamamoto
Autonomous Vehicle Simulation

Master of Professional Engineering

2021

Alishan Aziz EE UWA
Hydrofoil Jet-Ski

Xiaochen Bi EE UWA
Autonomous Shuttle Bus

Jason Chu EE UWA
Autonomous Shuttle Bus

Minglong He EE UWA
Automated Tray Thickness Testing

Zhihui Lai EE UWA
Machine Learning for Autonomous Model Car

Nyi Myo Maung EE UWA
Deep Learning for Mobile Robots

Benn Ness Mech UWA
Hydrofoil Jet-Ski

Vladimir Pavkov Mech UWA
Hydrofoil Jet-Ski

Daniel Trang EE UWA
Autonomous Shuttle Bus

Zack Wong EE UWA
Autonomous Shuttle Navigation

Angelo Yu EE UWA
Deep Learning for Mobile Robots

2022

Matthew Connell Mech UWA
Autonomous Solar Boat

Thomas Copcutt EE UWA
Autonomous Vehicle Guidance

Lemar Haddad EE UWA
Autonomous Vehicle Guidance

Kai Han EE UWA
Automated Hydrofoil Balance Control

Fraser Loneragan EE UWA
Deep Learning with GPUs

Hadi Navabi EE UWA
Design Platform for Robot Manipulators

Shao-Ming (Tim) Tan SE UWA
Autonomous Shuttle Bus

Jairus Wong EE UWA
EyeSim Virtual Reality System for Robot Simulation

Zhewei Zhong EE UWA
EyeSim: EV Charging and Monitoring

Research Activities

Students test out the model electric boats they designed at the Reid Library Pond

CIIPS Research Labs

Automotive Lab

Professor Thomas Bräunl

REV–Eco (Electric Hyundai Getz); REV–Racer (Electric Lotus Elise); Formula–SAE Electric; Formula–SAE Autonomous; BMW X5 Drive-by-Wire, Electric Scooter; Electric Jet Ski; Electric Hydrofoil; Autonomous Electric Shuttle Bus.
Location: Mech G.25

Robotics and Automation Lab

Professor Thomas Bräunl

Intelligent mobile robots; robot manipulators, factory automation line, embedded systems; image processing; simulation. Location: Mech. Eng. G.01

Smart Grids Lab

Adjunct Professor David Harries

Smart grids; distributed generation technologies; thermochemical energy storage systems; impact of electrical vehicles on electricity supply systems.

Student team developing software for autonomous driving

Automotive Lab

Professor Thomas Bräunl

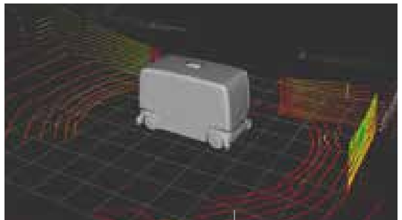
The Automotive Lab was established in 2008 and is dedicated to research on electric and autonomous vehicles. The Automotive Lab currently houses two Ligier electric shuttle buses, a BMW X5, a Hyundai Getz, a Lotus Elise S2, a Formula SAE-Electric race car, an autonomous FSAE-Electric race car, an electric Jet-Ski, an electric hydrofoil, and an electric scooter. The Engineering Faculty's Renewable Energy Vehicle Project (REV) is running in this lab. Details can be found at http://REVproject.com

Autonomous Electric Shuttles

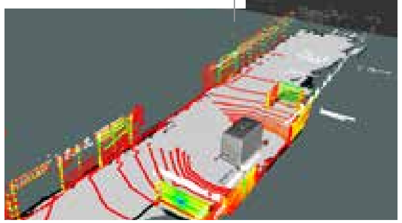
For our two electric shuttle buses, *n*UWAy-1 and *n*UWAy-2, we have built a full software stack from scratch, based on Linux with ROS-2 and its associated libraries. The shuttle already comprised eight Lidar sensors (4 x Sick, 2x Velodyne, 2x ibeo Lux), which we augmented with two Flir cameras and an RTK-GPS system donated by SBG, France. We also added an Nvidia Orin as an additional compute unit and a high-speed switch to accommodate all new sensors.

We are conducting active research on three major approaches to autonomous driving, which we will be combining to a hybrid and, overall, more reliable system. These are—

- RTK-GPS based Navigation. This is how most commercial shuttles currently drive.
- Lidar-based Navigation. This is how our shuttles currently navigate on the university campus.
- Vision-based Navigation. This will be our navigation mode on public roads in combination with RTK-GPS.



Lidar navigation maps generated by the autonomous shuttle



Dynamic Obstacle Avoidance

Kieran Quirke-Brown

At the start of 2020 the REV (Renewable Energy Vehicle) Project acquired an electric Autonomous Shuttle bus for the purpose of developing software that could run in different environments. The vehicle arrived as an empty shell with no internal software but did have 8 LiDARs, 2 cameras and a simple GPS. To drive the wheels it has a set of PLCs that accept CANbus messages, these messages are currently encrypted and not accessible by the team. In addition, these PLCs also act as a safety system using the lowest four LiDARs to build a safety curtain and cutting power to the motors when it drives too close to an obstacle. It has two drive modes, the first mode uses a controller in "manual" mode and second mode uses CANbus messages, sent from the onboard PC running autonomous software, which is the "Autonomous" mode. Since the CANbus system is encrypted the team cannot replicate or send messages to the autonomous system. To overcome this issue the vehicle was fitted with a new control board, developed by the team, to act as an interface between the software on the PC and the PLC drive system by replicating the manual drive CANbus commands. To improve the accuracy and computation performance of the system a second PC was added as well as an improved GPS with inbuilt IMU sensor. The second PC is a nVidia Jetson Orion which has an inbuilt GPU that can be used for tasks like image processing and implementing machine learning.

Development began in ROS (Robot Operating System) integrating LiDAR, IMU and RTK-GPS data to build a map and plan dynamic global plans across the campus. One of the limiting factors of this technology around the world is how these vehicles interact with unknown local obstacles such as people and signs which only occupy a space temporarily. At this moment the primary method for dealing with this is stopping before a collision occurs and then having a manual driver take over. This limits the uptake of the technology especially in dynamic environments such as a university campus. To improve the uptake of this technology the REV team has worked to improve this starting with the evaluation of existing technologies to

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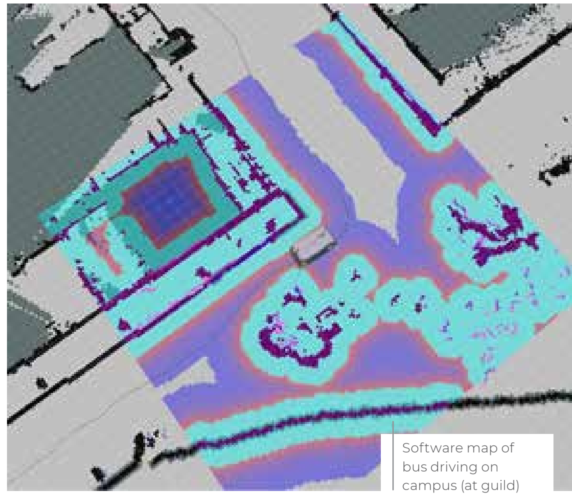
The 2020 team with the electric autonomous bus in it's original state

The *nUWAy* as it is now, doing the rounds of UWA Crawley Campus



Software map of bus driving on campus (at guild)

../from p9

see how well they perform in the real world on a campus environment. It was found that many of these algorithms, used primarily in small robots, would act sporadically and confuse surrounding pedestrians. Additionally, they lacked the forward thinking of a person to make predictions on changing scenarios which led to less than optimal behaviour. Lastly, the system lacked simple recovery behaviours for unknown situations and was at times unreliable due to the non-sequential startup sequence.

To resolve these issues the team started by upgrading to the more modern ROS2 which could incorporate newer features such as recovery behaviours, using navigation 2, and keep-out zones which improved safety without affecting localisation. The team also remodelled the launch sequence with a monitor node that would start key systems first in a more reliable and sequential order. This was important as the software struggled to run when launched from the ROS2 system normally. Additionally, the monitor node was able to detect node failures and restart nodes so that the system could keep running uninterrupted. This was another feature lacking in the original ROS and ROS2 system. The team has also been working towards improving the local planner which controls the drive system in a local area. As mentioned earlier the current technologies either use no obstacle avoidance at all or use obstacle avoidance but results in sporadic behaviour and causes confusion for onlookers. The system has been updated to remove complexities and take more appropriate actions such as slowing down instead of immediately diverting from its path. The next goals of the project are to incorporate more camera based features to "personify" the driving, making decisions based on future predictions, and incorporate AI and machine learning algorithms.

Finally, the project has expanded with the purchase of a second shuttle bus which is currently being retrofitted before being sent to Eglinton, a new suburb in the Northern region of Perth. This shuttle will run on the public roads using neural networks and RTK-GPS to service the needs of the public in that area and promote the technology to the wider community. (More about this initiative on page 13).

Mapping

Yuchen Du

Mapping is the process of recording information about the environment in which the vehicle operates. Simultaneous localization and mapping (SLAM) is the technology by which autonomous vehicles are able to gradually create a map using onboard sensors, and concurrently achieve self-localization for unknown pose and environment. A critical issue in SLAM is the drift phenomenon, which is the accumulated error over time. In an unknown environment, the vehicle estimates its current pose based on its previous estimated pose and current sensor readings. The sensor readings normally have noise, so this error will accumulate in the recursive estimation process. In order to solve this issue, we model the trajectory estimation problem as a pose graph shown in Figure 1.

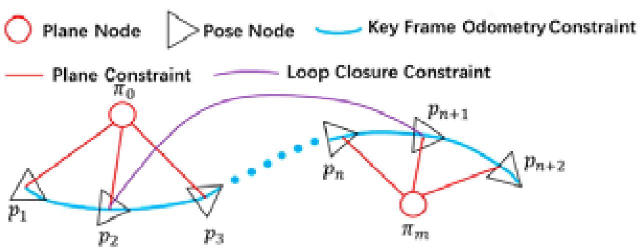


Figure 1. Pose graph optimization

The nodes in the graph represent the poses of the vehicle at different times and the poses of different landmarks in the environment, which are items to be estimated. The edges in the graph represent the transform between poses, the sensor measurements between poses and landmarks and the loop closure constraints. Using the states to be estimated and the constraints between them, the corresponding residues can be derived and a nonlinear optimization problem is formulated. By minimizing the total error, the optimal trajectory can be derived.

The open source 2D SLAM technology Google Cartographer, has been integrated in our *nUWAy* research platform, using lidar measurements to build the campus map offline as shown in Figure 2.

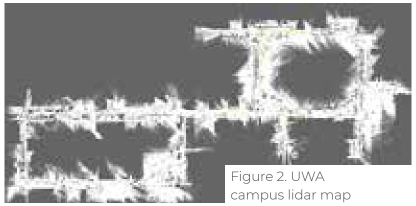


Figure 2. UWA campus lidar map

Global path planning is responsible for creating a collision-free path from the starting point to a given destination. The global path planner used on the *nUWAy* bus is the SBPL lattice planner, which can generate paths by combining a series of motion primitives. The planner considers both obstacle constraints and vehicle kinematics constraints. In our case, we customized the motion primitives to fit *nUWAy*'s kinematics (e.g. bidirectional movement, steering constraints), so that it can generate a kinematically feasible path in the campus environment, which can be directly used as a reference path for the local planner. Figure 3 shows a global path example.

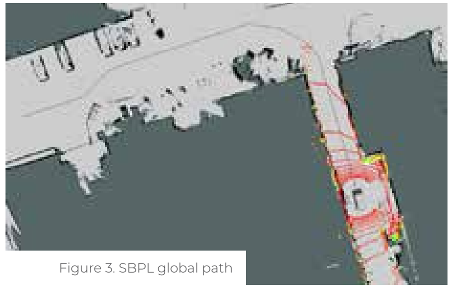


Figure 3. SBPL global path

The purpose of the local path planner is to generate control commands based on the detected objects which are not recorded on the map and the global reference path. This allows the vehicle to follow the global path while avoiding obstacles that are not on the map. The local path planner on *nUWAy* has been developed by us and consists of a pose follower module and a speed scaling module for safety reasons.

The global path is created as a series of waypoints, which are blended by a PID controller, giving steering command to drive the vehicle towards the next waypoint (Figure 4).

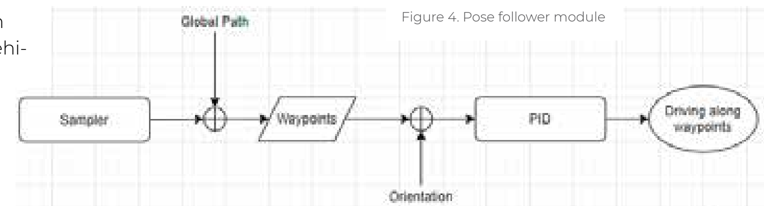


Figure 4. Pose follower module

The safety speed scaling module uses four lidar sensors that are constantly checking the area surrounding the shuttle. As objects in relevant areas approach the vehicle, the vehicle speed will gradually drop at the corresponding ratio. When there are multiple objects (e.g. pedestrians) approaching the shuttle, multiple corresponding driving speeds will be calculated and only the minimum speed executed (Figure 5).

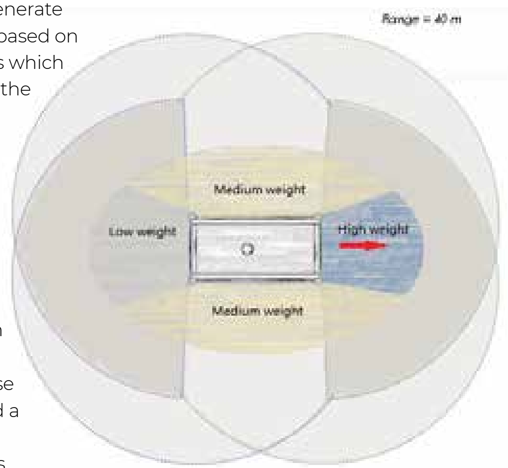


Figure 5. Safety checking areas

Remote Northern WA High School Visits

Kieran Quirke-Brown

In 2022, UWA worked together with the Poly Farmer Foundation to demonstrate to students in remote communities some of the work we do at UWA. Three students were selected to represent UWA and take one of the autonomous shuttle buses to three high schools: Carnarvon Community College, St Luke's College (Karratha) and Newman Senior High School. At each school the UWA representatives gave a presentation on who we are and what we do and then demonstrated the autonomous shuttle bus's capabilities.

The students loved the experience of riding on the bus and were fascinated by the safety features on board. It was noted by some of the teachers that several students who have never shown any interest in anything, were highly inspired by the autonomous shuttle bus. In Newman many of the locals also came by to see what was happening.

On reflection, with the coordinating schools it was determine that the demonstration was considered a complete success with many students being inspired. There are now talks about what else UWA can bring to the remote communities for students to get more exposure to technology.

The *n*UWAy arrives at Carnarvon

Demonstration to Carnarvon Community College Students

Demonstration to students of St Luke's College, Karratha

Presentation at Newman College

The *n*UWAy-2 launch at Amberton Beach, Eglinton

Amberton Beach Road Trial

Kieran Quirke-Brown

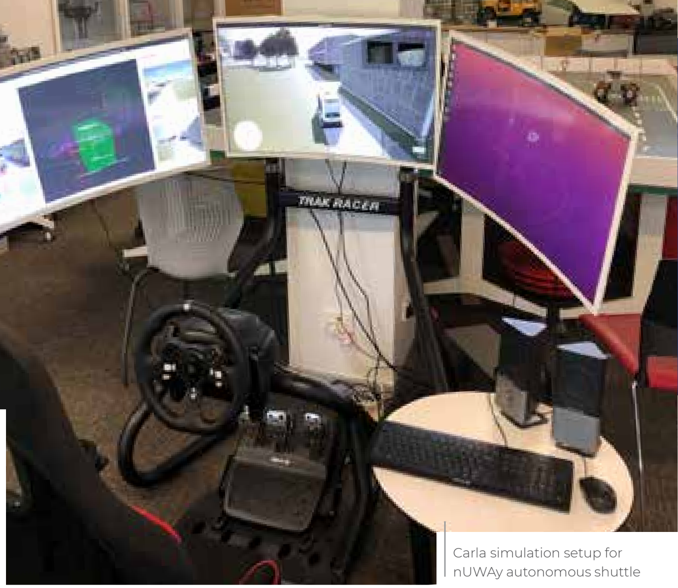
The 5th of December 2022 was the launch for the on-road trial of our second autonomous shuttle bus *n*UWAy-2 in the suburb of Eglinton between Marmion Avenue and Amberton Beach. The shuttle will provide an easy access to the beach for the residents of this new suburb.

Developer Stockland aims to bring up-and-coming technology to this community. The aim is to gain community involvement and provide a service to the general public while doing autonomous vehicle research at the same time. The launch was attended by many parties including the Mayor who was excited to see the technology in action and what it would mean for her community.

The team will be working in Eglinton for the next few months to get the Shuttle operational for its three-year trial. Over the next few years we hope to improve the system to become an on-demand service and require little intervention by the onboard safety officers.

The shuttle bus project has been funded by—

- DyFlex Solutions
- C.D. Dodd Metal Recycling
- UWA School of Engineering
- UWA Business School



Carla simulation setup for nUWAy autonomous shuttle

Autonomous Vehicle Driving Simulation

Zhihui (Eric) Lai

A simulation environment for the autonomous shuttle bus was designed based on Carla as a hardware-in-the-loop (HIL) system, which was later converted to a pure software simulation, as the HIL component did not improve the performance or accuracy of our system.

As part of the simulation environment, a digital version of the whole UWA university campus has been developed (see Figure 1). In addition, a 3D shuttle bus model was created as the main autonomous vehicle (see Figure 2).

The simulator has two control inputs: A steering wheel with accelerator and brake pedals (Logitech G920) and keyboard input. Users can conveniently set up and execute experiments with these controls and buttons. For simulator operation, we implemented six different modes;

1) Manual drive mode—Users can drive the simulated shuttle bus manually using the steering wheel and pedal or keyboard control. This mode is often used to collect lidar point cloud data (see Figure 3) to generate a pose-graph map and collect image data for the training of neural network models.

2) Lidar autonomous drive mode—Once a pose-graph map has been generated in manual drive mode, the simulated shuttle bus can drive autonomously from one place to another on an optimised path using the navigation module in ROS 2. This mode is identical to the driving operation implemented in the real shuttle bus.

Figure 1. Simulated UWA campus, facing north

Figure 2. Simulated shuttle bus on UWA map

3) Computer vision autonomous drive mode—This autonomous driving mode uses OpenCV computer vision algorithms. By applying Canny edge detection and Hough line detection, the program can identify the lane's left and right boundaries (see camera image in Figure 3), determining the steering and throttle command. However, this approach has problems at intersections and has not yet been implemented in actual shuttle buses.

Figure 3. Generated Lidar point cloud

4) Neural network autonomous drive mode—This is an autonomous drive mode (see Figures 4 and 5) using deep learning neural network models. The currently employed model is a modified PilotNet that takes the front camera image as input and outputs steering angle and throttle control commands. This method can handle intersection with traffic lights and is planned to be implemented in the real shuttle bus.

Figure 4. UWA neural network drive demo

5) Mirror drive mode—This mode connects simulation with reality. The real shuttle bus constantly publishes position, orientation and camera data to the web. The simulator accesses this data, converts the GNSS coordinates to the simulated vehicle's map position and replaces the simulation camera image displays with the actual camera images. Therefore, the simulated shuttle bus mimics the driving behaviour of the actual shuttle bus. This mode helps users monitor the actual shuttle bus remotely.

6) Carla built-in autonomous drive mode—This mode extracts all the traffic information from the simulator program, including traffic light states, distance to other objects and current location. With these information, the algorithm is able to drive in the center of the road and randomly turn at intersections. This mode is often used to generate traffic and collect image data for the training of neural network models.

Figure 5. Carla Town01 neural network drive demo

The REV Vehicles

Over the 15 years that the REV Project has been running, the following vehicles have been built and/or modified by students.

REV Eco
Electric conversion of Hyundai Getz:
DC drive system, 28kW, 144V, 13kWh, 80km range.

Autonomous Electric Shuttle Buses—*nUWAy*
48V, 15.36kWh, 8 Lidars, 2 cameras, IMU, RTK-GNSS.

Formula SAE Electric car
4-wheel drive system with wheel-hub motors, torque vectoring, 60kW, 52V, 8kWh.

REVski
Electric conversion of Sea-Doo Jet Ski: 4-TEC, 96V, 50kW, 7.6kWh, 30min. drive-time.

REV Racer
Electric conversion of Lotus Elise: S2 3-phase DC drive, 75kW, 266V, 16kWh, 100km range.

Autonomous BMW X5
Drive-by-wire, laser scanner, GPS, IMU, camera.

Autonomous SAE Electric car
Twin DC drive motors, 13kW, 48V, 4.3kWh, drive-by-wire, laser scanner, GPS, IMU, camera.

REV Waveflyer
Twin 5kW shrouded DC motors, 48V, 2kWh, 30min. drive-time.

Electric Hydrofoil research on automated stability and height control

Electric and Autonomous Watercraft

Our first Australian electric jet ski which we completed in 2015 was a great success and we are now seeing the first electric jet skis from commercial manufacturers.

For the next generation, in collaboration with start-up Electro.Aero/Electro.Nautic, we built an electric hydrofoil, consisting of an electric jet ski mounted with foils. This EIFoil has a range of about five times longer than an equivalent electric jet ski. However, it is extremely hard to control for the rider, so we are working on an automated control system for balancing and height control.

The Electric Jet Ski

Another marine project is the autonomous solar boat, a model catamaran, acting as our development platform for unmanned surface vessels.

The EIFoil

Pierre-Louis Constant

The EIFoil project has been a major focus over the last three years, where we aim at stabilizing a craft which hovers a few decimeters over the water surface. The outcome is to develop a high efficiency propulsion for marine craft.

We have had several successes on record, with substantial difficulties either overcome or identified, and solutions to experiment with.

The bulk of the produced work involved both designing of the hardware and the software that makes the controller, as well as designing watertight and durable enclosures for the power and control electronics.

The trials conducted in late 2021 allowed us to confirm the control model of the jet ski and validate the base stabilisation process including altitude control, and produced substantial feedback in terms of durability of the componentry.

Throughout 2022, we reviewed this feedback and produced a new generation of controller, equipped with an industrial single-board computer and a specialized interface card.

The newer controller software is much more involved, and has the following features:

- External hardware interrupt driven control loop with hardware set refresh rate, and minimal latency for the production of the output signal. Execution of code timing is important. The ultimate goal is to produce a hybrid controller with both an event-driven Linux system, and a real-time deterministic controller which can be accessed via shared memory utilising the PRU subsystems.
- The controller refers to a data structure that can easily be modified or upgraded, and the controller routing can be done in an almost human readable manner.
- Whilst the based control loop is driven by the Digital Motion Processor output of the IMU, the controller handles high level communication protocols such as serial, Bluetooth and CAN bus. This was achieved by implementing a data server to handle the asynchronous communications from the battery monitoring system, the motor controllers, the distance sensors, and Bluetooth link. This server architecture offers an easily extendable and unified way of adding more sensors or signals.
- An added extended logging capability to the controller allows us to understand the process better, evaluate the action of each part of the system, and apply corrections.
- All the data structure is streamed to an Android tablet. A custom app allows us to browse all the variables of the system , and update the controller parameters, PID gains, monitor the input outputs, etc.

The commissioning of the system is now complete and we are currently conducting extensive trials to tune the craft. The EIFoil has returned to the water since September 2022 and undergoes regular weekly testing sessions, as part of a data collection and analysis campaign.

Autonomous Solar Boat

Pierre-Louis Constant

The solar boat is an environmentally friendly robotic autonomous vehicle, which can operate in lakes, in the Swan river and in sheltered waters.

The project was initiated in 2017 and aims to provide a self-powered robotic marine platform. We developed the robot, the ground control station and the plugins to an existing software and control protocol.

In 2021–2022, the upgrades were mostly themed on the deployment and operations of the boat—

- The ground control station was upgraded with an internally designed solar powered battery bank, which allows us to set up a control station anywhere, and have a full day of operational autonomy.
- The communication link was improved to Ubiquiti AirMax bullet M5, offering 300MB/s over several kilometers range.
- RTK-GPS positioning corrections providing an accuracy of a few millimeters, generated at the ground control station, and propagated by the LR link.
- Live transmission of video feeds, and multiple cameras are now being easily handled by the LR link.
- We also mounted a client sonar equipment through the LR link to produce live 3D depth profiles via the Navionics app at the ground control station.

In 2023 the focus is on the precision and propulsion capability of the boat to plan for the production of a larger, fully sea-going unit—

- We are integrating more marine instruments such as wind sensors, depth sounder, and lidar to improve the precision of the navigation collision avoidance capability of the boat.
- The propulsion will be improved, with the addition of two side thrusters, thus providing a station-keeping capability.
- The power distribution needs improvement to accommodate all the new sensors more neatly, and is currenty designed.
- The software QGroundControl is being improved by means of plugins to display Electronic Navigation Charts (ENCs) in order to assist with the passage planning and mission generation. We also are developping additional plugins to display the wind and depth profiles, similarly to nautical instruments.

Autonomous boat (with solar panels removed)

Whilst it is of modest size, the Autonomous Solar Boat is a very versatile development platform and it allows us to discover the waterways of Perth in a productive manner!

The electric jet-ski has been funded by—

- The Australian Medical Association (AMA)
- Submersible Motor Engineering Perth (SME)
- Total Marine Technology (TMT)
- Altronics

The hydrofoil project has been funded by—

- Galaxy Resources
- UWA School of Engineering
- UWA Innovation Quarter
- RiverLab

EV Charging in Western Australia

Our initial EV charging infrastructure in the Perth Metro areas was installed in 2010 and 2011—the first IEC Type-2 stations in Australia—followed in 2014 by the first CCS-DC station in Australia. In 2022, the AC stations had become unreliable and mostly obsolete, so we had to replace them with new dual-outlet stations from CirControl. To supplement the 50kW Tritium CCS/CHAdeMO DC charger, we installed a new high-performance 160kW dual-CCS charger from Siemens at UWA Engineering's new EZONE building.

AC chargers continue to be sponsored by Allkem (formerly Galaxy Resources) and Synergy, while the Tritium charger was originally donated by a Perth individual, who prefers to stay anonymous.

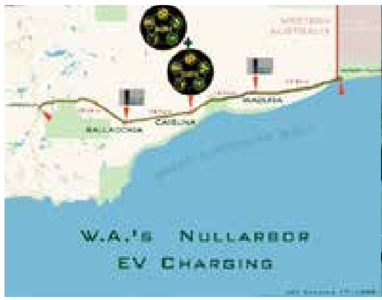
A fundraising campaign was conducted to fund the new Siemens charger with donations by David Lloyd, CD Dodd Metal Recycling, Tesla Roadster Inc, Tesla WA Slack Forum, Tesla Owners WA and Tesla Owners Australia, plus lots of individual contributions, with matching funding provided by UWA.

The link between Esperance in WA and the South Australian border across the Nullarbor was part of our proposed charging network for WA, but was left out in the government funded version. We therefore conducted a second crowdfunding campaign to "Close the Gap". We successfully raised funds over $90,000, which allowed us to purchase two 25kW Delta DC-chargers plus an innovative 'BioFil' charger, which uses waste frying oil from roadhouses in a generator to power a 50kW Tritium DC charger. Since the frying oil comes from locally grown canola plants, this constitutes a closed cycle with net zero greenhouse gas emissions.

Photo credit: Plugshare

Electric Harley Davidson using the Siemens charger

New dual AC-charger at UWA Computer Science



Our 2018 'EV Charging Infrastructure Report' for Western Australia has finally been adopted by the Western Australian State Government and is being implemented with some changes by utilities Synergy and Horizon Power. Tenders have been issued and installation is expected to be completed by 2024. With the adoption of EVs now on an exponential growth curve, this network will be a major milestone and the fundamental requirement for enabling state-wide and nation-wide travel using electric vehicles.

Corporate sponsors:

Allkem, synergy, Dodd, DyFlex Solutions, Altronics, TeslaWA Slack Forum, Tesla Owners Western Australia, AUS TIM Sustainable Timber Solutions, Fleetwood Australia, Tesla Owners Australia

Robotics and Automation La

Professor Thomas Bräunl

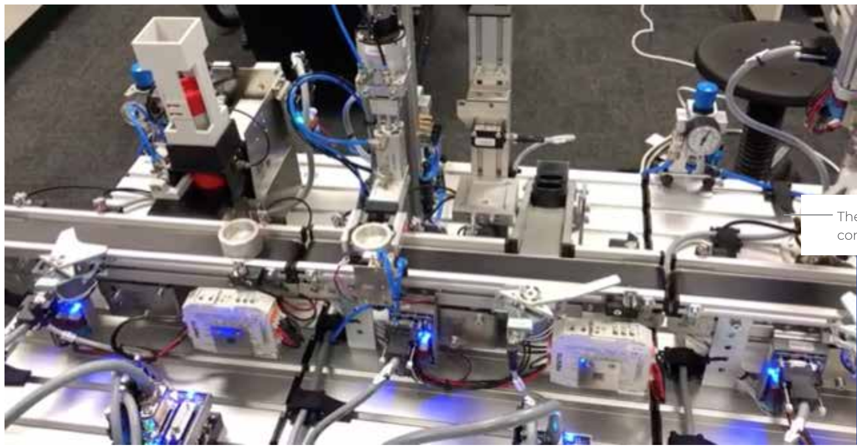
The Robotics and Automation Lab was established in 1998 and is dedicated to research on intelligent autonomous mobile systems. Using embedded systems, over 50 mobile robots have been designed and built in the lab, while the development of simulation systems also plays a major role in the lab's research efforts. Details can be found at: RobLab.org

In 2021, the Robotics Lab moved to its new location, the Clough Engineering Centre in the Mechanical Engineering building. This new site combines the areas for robotics research, robotics teaching, and also the newly established UWA Robotics Club. The combined spacious area has great visibility and is adjacent to the UWA Makers Club, which is very valuable when building or upgrading robots.

Automation

Our automated production street from Festo is used for teaching in the Automation unit. We have five industrial stations, linked by conveyor belts, which can be freely programmed by students. Each station carries out a particular task, from fetching and measuring parts, to assembling and pressing, until finally sorting the finished products.

This automation equipment uses standard industrial components and therefore gives students an important industry-relevant experience and skills for their future careers.



The Festo street conveyor system

Robot Manipulators

The lab uses three UR5 robot manipulators for teaching purposes. Students work on group projects for various manipulation tasks with these robots. These include camera sensing, motion planning and task execution. The robots are being used for labs by Engineering students as well as by Architecture/Design students.

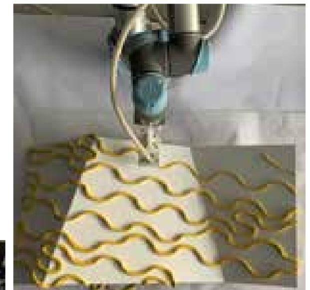


Photo credit: Santiago Perez

Senior Lecturer Santiago Perez of the UWA Design School using the UR5 robots for design work

Inset top right: fine tasks are executed by the robot manipulators

The Nachi robot manipulator (150kg payload) was donated to UWA by RV manufacturer Fleetwood Australia and is now a centerpiece of the new EZONE building. We use this robot for student projects in the new Automation and Robotics degree as well as for cooperative work with areas spanning from 3D concrete printing in Mechanical Engineering to timber sculpture manufacturing in Architecture. Aus_Tim is sponsoring the project of constructing a large robot-generated sculpture with the supply of timber pieces.

The Nachi Industrial Robotics Manipulator

Hadi Navabi

Block Programming Interface (NachiOS)

To provide accessibility to the wide diversity of individuals that may be interested in working with the Nachi robotics manipulator, and due to their varying range of experience coming from different scientific fields, industries, and backgrounds, there is a clear need for a simple method of communication and programming for the Nachi robotics manipulator.

Nachos, also known as NachiOS (Nachi Operating System), is a refined, and simple to use, interface software. Its objective is to bring together and link Nachi's internal functionalities into a formal and understandable Block-programming user interface. It aims to provide assistance to all potential users of the Nachi robotics manipulator, regardless of their dissimilar sets of expertise.

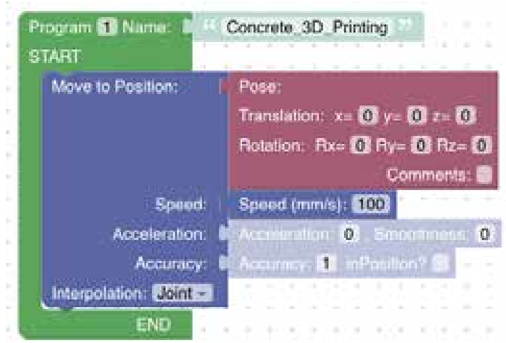
Block Programming is a visual-based programming language that is designed for individuals with limited programming knowledge and expertise. It allows for easy visualisation of all the available features of the language and enables easy drag-and-drop interactivity of blocks for fast and easy development. The blocks represent the most fundamental functionality of the language and can be grouped, attached, or nested together to create a larger program.

https://nachios.vercel.app

Nachi robot stacking timber sticks in Jenga fashion

Concrete 3D Printing

In collaboration with the MPE Robotics students (Hadi Navabi), Civil Engineering students (Mitchell Grey and Monica Ngo) and other students and staff, one of the most anticipated projects was fulfilled and the possibility of creating complex 3D structures



in concrete was proven. The research team successfully managed to set up and print a 10-layered structure using the Nachi industrial robotics manipulator.

Following the addition of I/O functionality and the installation of the industrial gripper on the Nachi robotics manipulator, a wide range of opportunities were made possible. Similar to the Concrete 3D Printing project, the gripper enables the interaction and manipulation of objects in the real world. The Jenga project was implemented to understand the potentials and limitations of the gripper interactivity with real-world objects.

Mobile Robots

We refurbished five 'Pioneer' mobile robots new industrial PCs as compute units and all new sensors for project work in the Mobile Robots unit. Sensors include SICK Lidars, Oak-D stereo cameras and Phidget-Spatial inertial measurement sensors. The Pioneers can be programmed with either the ARIA or the ROS interface and are being used for waypoint-following and mapping/navigation tasks.


Pioneer robots

As an entry-level autonomous driving project, we created the Autonomous Ride-on Car together with the UWA Robotics Club as a STEM project for high schools. The conversion of this kids' ride-on car is fairly simple and requires only limited skills, so it can easily be completed as a high school project. In addition to the car chassis, we use a Raspberry Pi plus a GPS as the basic equipment, which of course can be extended in many ways with additional sensors and software. The first task for the high schools is to recreate our vehicle design, then implement their own software for GPS waypoint following.

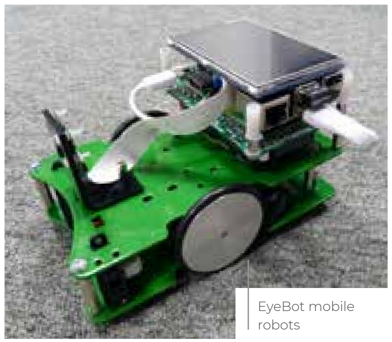
Participating high schools so far are—

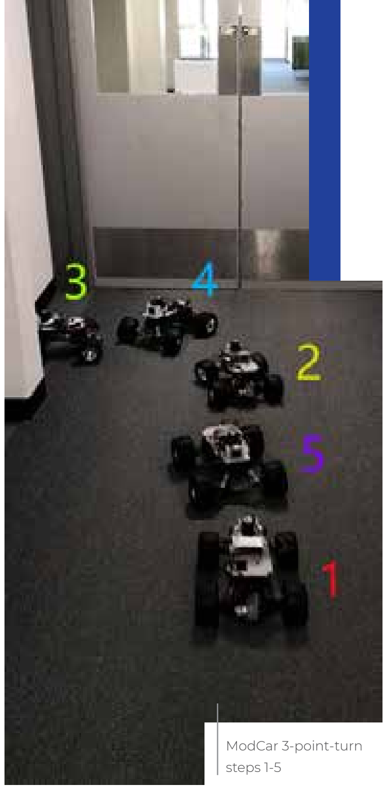
- Perth Modern School
- Sacred Heart College
- Bunbury Senior High School
- Waroona District High School
- Seven Oaks Senior College

See details at: Roblab.org/rideon/

Our compact "EyeBot" mobile robots are used together with their matching "EyeSim" simulation system for labs in the Embedded Systems and Mobile Robots units.


Autonomous Ride-on Car (ARC)


EyeBot mobile robots



ModCar 3-point-turn steps 1-5

Autonomous Driving Robot

Zhihui (Eric) Lai

This project implements a Lidar-based autonomous driving base line. The project utilized NVIDIA's PilotNet and performs end-to-end deep learning research by training the vehicle's image data input from obstacle distances delivered by the on-board Lidar. Two novel memory models were developed to to address the shortcomings of PilotNet.

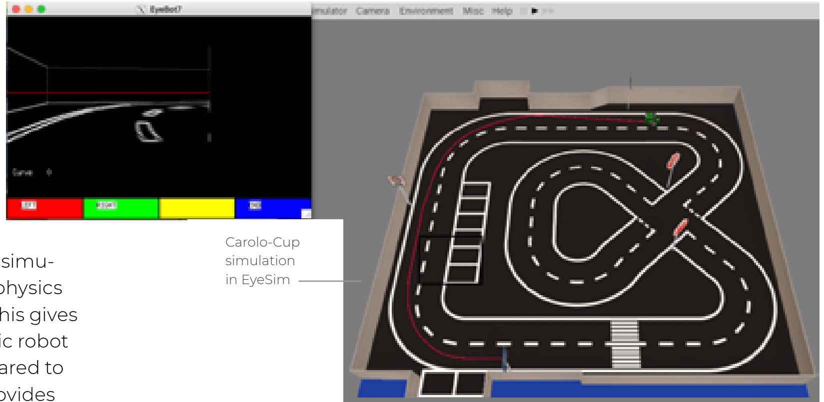
PilotNet works only for simple driving tasks, such as lane following and driving between two walls, However, for complex driving tasks in indoor environment, such as making a three-point turn at a dead-end or recover-ing from a poor position, PilotNet will fail. This research introduces visual end-to-end navigation and proposes two novel models: CNN + LSTM and CNN3D, aiming for complex autonomous driving tasks in an indoor environment. All source code is available on GitHub: https://github.com/zhi-hui- lai/ModCar_Project.git


CNN+LSTM model racing with Lidar model in an EyeSim maze map

Simulation

Our EyeSim-VR robot simulator is based on the physics game engine Unity. This gives us much more realistic robot movements as compared to older versions and provides native versions on all common platforms, including MAC OS, Windows, Linux, mobile phones, tablets, and even smartwatches. Special virtual reality versions of EyeSim have been developed for Oculus Quest, Go, Rift and HTC Vive.

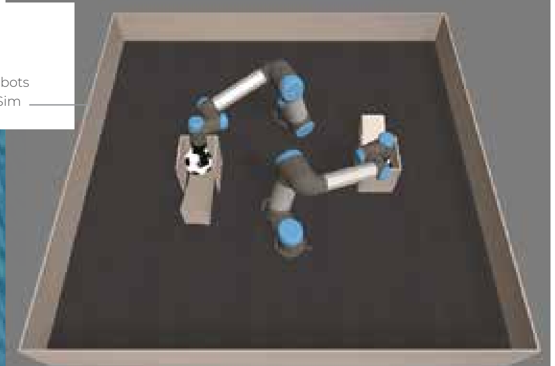
EyeSim can simulate multiple mobile robots, autonomous vehicles, boats/submarines and robot manipulators.



Carolo-Cup simulation in EyeSim

Micromouse maze simulation in EyeSim

Mako submarine simulation in EyeSim



UR5 robots in EyeSim

Robot Soccer in EyeSim

Formula-SAE car in EyeSim

Autonomous Security Vehicle

Elliot Nicholls

An autonomous and robotic security vehicle known as the ASV was developed at UWA by Master's students using leading-edge technologies and engineering techniques. It replaces the need for security guards to patrol perimeters and regularly test perimeter intrusion security devices (PIDs). The ASV is a Western Australian initiative imagined, designed, developed and manufactured here. The ASV has been funded through an industry collaboration between the Department of Justice, Honeywell and Stealth Technologies.

Smart Grids Lab

Adjunct Professor David Harries

The Smart Grids Lab is involved in investigating electric vehicles and how they impact energy policy. This work includes the The UWA REV Project on analysis and modelling of EV charging behaviour.

David's research areas include energy policy, the options for curtailing greenhouse gas emissions from the energy sector, techno-economic analyses of emerging renewable energy generation and energy storage technologies, and the assessment of the impacts of distributed energy generation, distributed energy storage and electric vehicle charging on electricity supply grids. He is actively involved in the use of hybrid solar and battery off-grid power supply systems as an alternative to using the electricity network to supply electricity to rural properties.

David has also reviewed a large number of journal papers for different journals such as Renewable and Sustainable Energy Reviews and has been invited to act as guest editor for a special issue of the journal Sustainability on the topic of sustainable transport and electric vehicles.

Work over the past few years has included contributing to a report on an electric vehicle public fast-charging network for Western Australia. The report identified the optimal locations, charging station types (kW) and numbers of stations per site for roads on the major road network in Western Australia. The work included a timeframe for the roll out of the public EV fast charging network based on forecasts made of future EV take up rates in Western Australia. The work also resulted in the submission of two journal papers.

David is currently working on a project advising the Maldivian government on the electrification of transport in the Maldives. He is currently acting as an advisor to three UWA Engineering PhD students. David is also an assessor for ARC research grant applications.

Student Activities

Robotics Hackathon

Fraser Loneragan

On the 7th and 8th of September, the UWA Robotics Club held its first hackathon, Finding Loomo the Segway! Student teams competed in the two-day event, facing multiple challenging but rewarding autonomous driving challenges.

The challenges were oriented around three main robots: The Pioneer Robots, Loomo the robot Segway and the Microsoft HoloLens. Participating teams developed their skills using ROS and OpenCV while programming the pioneers to complete autonomous driving tasks. They also had to recognize objects/colours, which developed their experience with computer vision. The students utilised Android Studio to program Loomo and made it drive specific patterns as part of a secondary challenge. Finally, some teams got to interact with our Microsoft Hololens and experience the new technology as they competed!

Thank you to all the participants for the time given and for putting in all the hard work over the two days. The spirit and the atmosphere created were great to see! The club received positive feedback from the event; students particularly emphasised how rewarding it was to implement the techniques they learned on the day.

We would also like to thank Professor Thomas Bräunl and Senior Lecturer Santiago Perez. who helped and supported us throughout the planning of this event and made this great success possible!

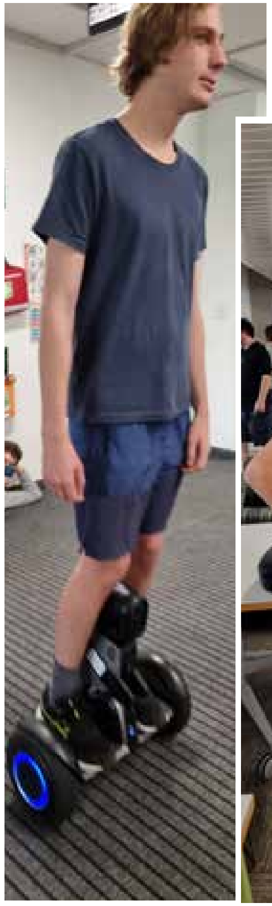


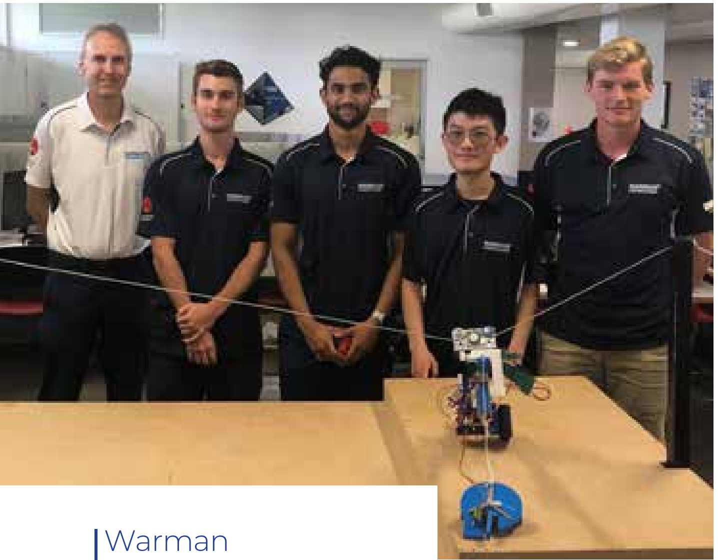
Photo: UWA Robotics Club – https://uwarobotics.com.au/

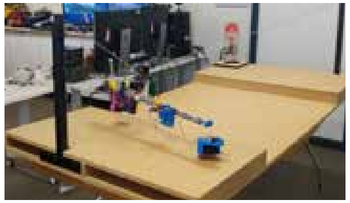
Robot Barista

The UWA Robotics Club members have their very own Robot Barista!

The coffee robot works by using a UR5 robot arm, which operates a commercial coffee machine to make an espresso shot.

The Robot Barista of UWA Robotics Club and Augment Technologies





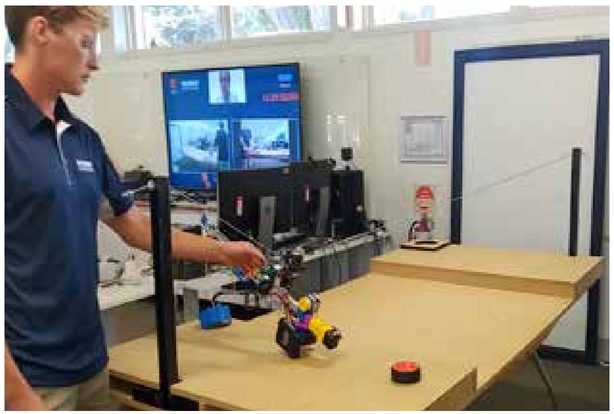
Warman Competition

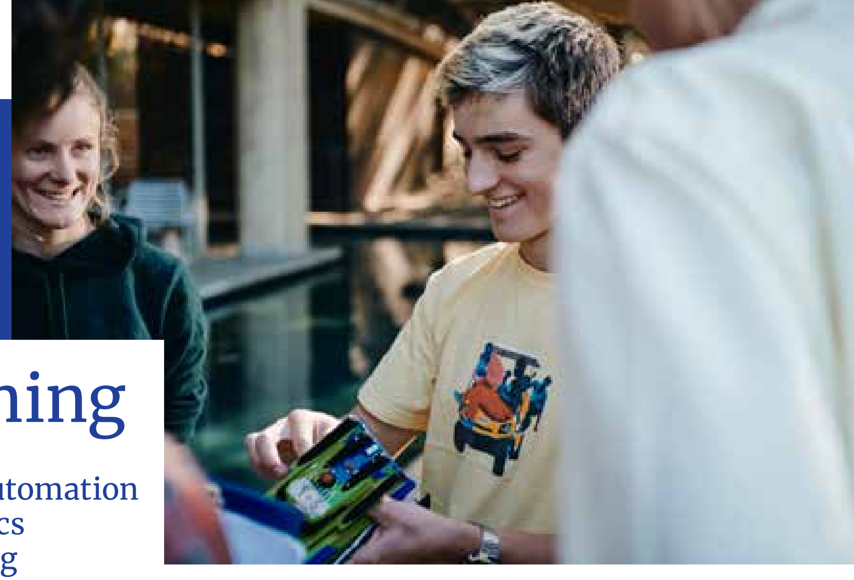
The Warman competition is Australia's oldest Mecha-tronics competition for students in Mechanical and Automation Engineering.

After a long absence, UWA participated again in the 2022 Warman finals. A team of Automation and Robotics students from the new unit AUTO3002 Mechatronics built a device that could automatically pick up a payload, transport it to the other side of a chasm, and then safely deposit it into a designated delivery area.

The robotic system was developed by Jonas Kluver, Charlie Teo, Pierce Brezmen, and Ovik Choudhury. It performed perfectly in both competition runs and scored full points for solving the given task.

Only beaten by teams with faster solutions, the UWA team finished up in 7th place out of 15 participants.





Teaching

Major in Automation and Robotics Engineering

The new Major in 'Automation and Robotics Engineering' started in semester 1 of 2022.

It is based on the three pillars of Mechanical, Electrical, and Software Engineering, augmented by several discipline-specific units in automation and robotics.

The diagram shows all units in this degree with color coding—blue for software units, orange for mechanical, yellow for electrical and green for general engineering units. In dark red are specialist automation and robotics units, while the four elective slots are white.

A new Industry Advisory Panel has been established for this new Major, which contributes to curriculum development and provides additional support for specialist units, through guest lectures and company site visits.

Bachelor of Engineering – Automation and Robotics Engineering Major
20/05/2022 – Study Plan - Commencing: Semester 1, 2023

** Offered in Both Semesters

Common Core Units

Year 1 Semester 1 2022	**MATH1011** Multivariable Calculus *Prereq: Math Specialist ATAR or MATH1722*	**CITS1401**** Comp. Thinking with Python *(or CITS2401** Computer Analysis and Visualisation)*	**ENSC1004**** Engineering Materials *Prereq: (Chem ATAR or CHEM1003) & (Phys ATAR or PHYS1030)*	**GENG1010** Introduction to Engineering (For Bridging move to Year 2)
Year 1 Semester 2 2022	**MATH1012** Mathematical Theory & Methods *Prereq: Math Specialist ATAR or MATH1722*	**CITS2002** Systems Programming *APS: CITS1001 or CITS1401 or CITS2401*	**ENSC2004**** Engineering Mechanics 1 *Prereq: (Physics ATAR or PHYS1030) & MATH1011 APS: PHYS1001*	**ELEC1303** Digital Systems
Year 2 Semester 1 2023	Elective/Minor	**CITS2200** Data Structures & Algorithms *Prereq: CITS1001 APS: An additional programming unit*	**GENG2004** Solid Mechanics *Prereq: ENSC2004, MATH1011 & MATH1012*	**ENSC2003**** Eng. Electrical Fundamentals *Prereq: (Phys ATAR or PHYS1030) & MATH1011; Co-req: MATH1012 APS: PHYS1001*
Year 2 Semester 2 2023	**ELEC2311** Digital System Design	**CITS3001** Algorithms, Agents & AI *Prereq: CITS2200*	**MECH2004** Engineering Dynamics *Prereq: ENSC2004*	**ELEC3020** Embedded Systems *Prereq: CITS1001 or CITS2401*
Year 3 Semester 1 2024	Elective/Minor	**CITS4402** Computer Vision *Prereq: software unit*	**AUTO3002 – NEW 2023** Mechatronics *Prereq: ENSC3020*	**AUTO4508** Mobile Robots *Prereq: software unit*
Year 3 Semester 2 2024	**MECH3424** Measurement and Instrumentation *prereq CITS1001 & ENSC3001*	**GENG3402** Control Engineering *Prereq: ENSC2004, MATH1011 & MATH1012*	**MECH3001** Mechanisms and Machines *Prereq: (CITS1001 or CITS2401), ENSC2004, & MATH1011 APS: PHYS1001*	**ELEC3016** Power and Machines *Prereq: ENSC2003 & MATH1012 APS: PHYS1001*
Year 4 Semester 1 2025	**GENG4411** Research Project 1	Elective/Minor	**AUTO4507 - NEW 2024** Robot Manipulators and Automation *Prereq: software unit*	**ELEC5506** Process Instrumentation & Control
Year 4 Semester 2 2025	**GENG4412** Research Project 2	**GENG5507** Risk, Reliability, Safety *Prereq: —, APS: IPE*	**GENG5505** Project Management *Prereq: —, APS: IPE*	Elective/Minor

Media Reports

Television Reports and Interviews

- ABC World News Australia, interview with Yvonne Yong, *Volvo stopping the import of petrol cars to Australia from 2026*, 8 Nov. 2022, 19:30
- Channel 10, *Biofil EV charging station for the Nullarbor*, 22 Dec. 2021
- Channel 7, co-broadcast
- Channel 10, 10 News First, *UWA students have become the first in Australia to develop a driverless shuttle bus*, Narelda Jacobs, 18 June 2021, 18:15
- West Digital Television (Albany), co-broadcast
- WIN Television, Western Australia, co-broadcast
- Channel 7, Seven News WA, *Students from the University of Western Australia Have become the first in the country to build the brains behind an autonomous shuttle bus*, Samantha Jolly, 18 June 2021, 16:13
- The World ABC News, *Phasing out fossil fuel vehicles in New Zealand*, interview with Beverley O'Connor, live, 9 June 2021, 20:30

Radio Interviews

- ABC Radio, Interview with Andrew Collins, *Election Programs for EV Charging*, 6 May 2022, 16:30
- ABC Radio, Morning with Nadia Mitsopoulos, *Transitioning to Electric Vehicles because of rising fuel prices*, interview with Nadia Mitsopoulos, 17 Feb. 2022, 9:00
- RTR FM, 92.1, *nUWAy Autonomous Shuttle Bus*, interview of Thomas Bräunl and Jai Castle with Jesse Begley, On The Record, 29 June 2021, 9:30
- The West Live, *How a driverless bus was taught to avoid UWA students*, interview of REV student Jai Castle, 18 June 2021, 9:27
- Mamamia Women's Media Network news podcast, The Quicky, *Busting Electric Vehicle Myths*, podcast interview with Claire Murphy, 13 Jan. 2021, 12:00, Sydney
- ABC Radio National, *Electric Vehicle Policy*, Interview with Jeremy Patrick, 15 Dec. 2020, 18:00
- ABC Radio National, *Electric Vehicle Charging Networks*, Program Rear Vision, Interview with Zoe Ferguson, 17 Mar. 2020, 11:00
- 2GB Sydney, 4BC Melbourne, 2CC Canberra, *Hydrogen Vehicles versus Electric Vehicles*, interview with John Stanley, 29 Jan. 2020, 15:00

Print Media

- Harvey-Waroona Reporter, Waroona District *High School students put STEM skills to the test with autonomous tour guide kart project*, Sean Van Der Wielen, 8 Nov. 2022
- One Earth, November Voices, *A net-zero future for freight, Electrifying the land-based freight sector*, CelPress, vol. 4, 21 Nov. 2021, p. (1519)
- Sunday Times, Seven West Media, Education Liftout, *Driving change*, 31 Oct. 2021, p. (1)
- Subiaco Post, *Free electric rides at Uni*, Louisa Wales, 16 Oct. 2021, p. 29 (1)
- The West Australian, *Software sabotage a road to ruin*, Olga de Moeller, Motoring Section, WestWheels Cover Story, 17 July 2021, pp. 6-7 (2)
- Western Suburbs Weekly, *Driverless bus a first*, 24 June 2021, p. 2 (1)
- The West Australian, *University of WA in Aussie first with student-designed driverless bus called nUWAy*, Ben O Shea, Uni's driverless bus a first, 19 June 2021, p. 41 (1)
- Subiaco Post, *Smart students build robot bus*, report by Lloyd Gorman, 18 June 2021, pp. 5+32 (2)
- The West Australian, Supplement 1, *Culture of innovation at UWA – UWA Robotics Lab and Renewable Energy Vehicle Project (REV)*, 16 June 2021
- The West Australian, *Perth Tech Charges Ahead*, West Business 19 Jan. 2021, pp. 18+35 (2)
- The West Australian, *Self-drive bus maps way for future automation*, Motoring Lift-Out, report by Olga De Moeller, 21 Nov 2020, p. 13(1)
- Subiaco Post, *Funding fillip for autonomous vehicle project*, 23 May 2020, p. 68 (1)
- West Australian Newspaper, *Getz conversion proves UWA's electric potential*, WestWheels cover story, by Olga De Moeller, full page article, 11. March 2020, p. 6 (1)
- Cambridge Post, *Hands-free driving*, Road safety minister Michelle Roberts opening new research centre

Invited Talks and Project Demonstrations

Talks

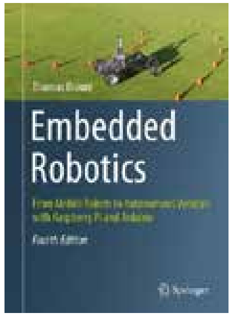
2 Sept. 2022	Invited Talk: *Automotive Future – Connected, Electric and Autonomous Cars*, U3A, Rockingham
28 April 2022	Invited Talk: *Electric Vehicle Charging*, Sustainability and Future Fuels Event, Perth
24 Oct. 2021	Invited Talk: *Electric Vehicles – Your Next Car*, Australian Conservation Foundation, Perth
16 Sept. 2021	Invited Talk: *Automotive Future – Why Support for EVs is Crucial for Population Health*, Road Safety Research Centre, Perth
8 June 2021	Invited Talk: *Electric and Autonomous Vehicles – From Zero Emissions to Zero Accidents?*, The Electric Energy Society of Australia (EESA), Western Power, Perth
8 Oct. 2020	Invited Panel Session: *iDrive – towards zero emissions*, Gemtek, Perth Airport
14 Sept. 2020	Invited Talk: *Electric and Autonomous Vehicles – The three major revolutions currently happening in the automotive industry*, The Institution of Engineers Sri Lanka, Western Australia Chapter
10 June 2020	Invited Talk: *Electric Vehicles for WA – Increasing Industry Sustainability through the Uptake of Electric Vehicles*, Industry Breakfast, AAPA, Australia, Online

Project Demonstrations

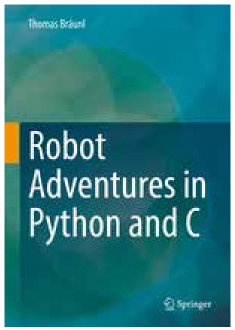
7 Dec. 2022	Robotics Lab demonstrations for Broome High School students
5 Dec. 2022	Autonomous Shuttle Bus nUWAy2 launch at Eglinton / Amberton Beach
29 Nov. 2022	Robotics Lab Tour for Group-of-Eight Heads of School / Heads of Department Workshop
22 Nov. 2022	Robotics Lab Tour for Equinor, Norway
11 Nov. 2022	Autonomous Shuttle Bus excursion and demonstration at Newman Senior High School
9 Nov. 2022	Autonomous Shuttle Bus excursion and demonstration at St Luke's College, Karratha
7 Nov. 2022	Autonomous Shuttle Bus excursion and demonstration at Carnarvon Community College
7 Nov. 2022	Robotics Lab demonstrations for Newman Senior High School students..
9 Oct. 2022	Warman Competition
14 Oct. 2022	Robotics Lab and REV demonstrations for UWA Engineering Alumni of 1983
29 June 2022	Robotics Lab demonstrations for Australind High School
14 June 2022	Robotics Lab and REV Lab demonstrations for Rio Tinto
24 Jan. 2022	Robotics Lab and REV Lab tour for Fortescue Metals Group (FMG)
17 Jan. 2022	Robotics Lab Tour for National Youth Science Forum (NYSF)
11 Oct. 2021	Robotics Lab Tour for Ellenbrook Men's Shed
30 Sept. 2021	Robotics Lab Tour for Early Offers Holders and new UWA students
15 June 2021	Robotics Lab demo for Coolbinia Primary School.
26 May 2021	Robotics Lab visit for TechWorks, Woodside
17 Feb. 2021	REV Lab and Industrial Robot Lab visit for Automation and Robotics students
13 Jan. 2021	Robotics Demonstrations for National Youth Science Forum, Perth
11 Dec. 2020	REV Lab and Autonomous Shuttle Bus demonstration for WA State government, Department of Jobs, Tourism, Science and Innovation
10 Dec. 2020	REV Lab and Autonomous Shuttle Bus demonstration for Roy Hill Mining
1 Dec. 2020	REV Lab visit and Robotics Lab visit for Sacred Heart College
1 Dec. 2020	REV Lab visit and Robotics Lab visit for Girls in Engineering program
1 Dec. 2020	REV Lab visit and Robotics Lab visit for Waroona District High School
16 Oct. 2020	REV Lab visit, The Institution of Engineers Sri Lanka, WA Chapter
7 Oct. 2020	REV Lab and Robotics Lab visit from Shenton College high school
30 Sept. 2020	REV Lab and Robotics Lab visit from Shenton College high school
5 March 2020	Robotics Workshop for Chuo University, Japan

Publications

Books



T. Bräunl
Embedded Robotics—From Mobile Robots to Autonomous Vehicles with Raspberry Pi and Arduino, Springer-Verlag, Shanghai, 2022



T. Bräunl
Robot Adventures in Python and C, Springer-Verlag, Heidelberg, 2020

Book Chapters

T. Bräunl, *Electromobility in Western Australia*, in A. Ludewig (Ed.), WAGBA 2021, Sep. 2021, pp. 38–40 (3)

K. Lim, S. Speidel, T. Bräunl, Chapter 8: *REView: A Unified Telemetry Platform for Electric Vehicles and Charging Infrastructure*, in Zaigham Mahmood (Ed.), Connected Vehicles in the Internet of Things, Springer International Publishing, 2020, pp. (52)

Journals

F. Hidalgo, T. Bräunl, *Evaluation of Several Feature Detectors/Extractors on Underwater Images towards vSLAM*, Sensors 2020, 20, 4343, MDPI, Aug. 2020, pp. (16)

M. Islam, M. Sheikh Sadi, T. Bräunl, *Automated Walking Guide to Enhance the Mobility of Visually Impaired People*, IEEE Transactions on Medical Robotics and Bionics, Aug. 2020, vol.2 , no. 3, pp. 485–496 (12)

T. Bräunl, D Harries, M. McHenry, G. Wäger, *Determining the Optimal Electric Vehicle DC-Charging Infrastructure for Western Australia*, Transportation Research Part D: Transport and Environment, 2020

Magazines

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Current **PhD Research**

Pierre-Louis Constant

Supervisor: Professor Thomas Bräunl

Autonomous Marine Vessels

A marine craft depends on two major elements to move through the water: its hull, that allows it to float and evolve through the water, and its propulsion ensemble, that in turn allows for movement and direction. The research for a more efficient marine propulsion process will necessarily involve progress on each of these components.

The current state of the art in electric motors, batteries and material technologies has matured to the point where the association of two efficient technologies, such as electric propulsion and hydrofoils, is not only possible, but shows symbiosis as the benefits of each compensates the drawbacks of the other.

Using hydrofoils and electric propulsion would allow on one hand to benefit from an environmentally friendly propulsion process that does not emit green house gases, and on another hand, to reduce substantially the general opposition to the movement in the marine environment, therefore extending the autonomy of the craft.

The key element that allows for this technological combination is the craft's control system, which should not only connect the two processes, but actively seek to benefit from each of them symbiotically.

In line with these considerations, the object of this research is to develop an automated control system for an electric personal water craft, fitted with hydrofoils, and apply it to a real-life, full size prototype.

Thomas Drage

Supervisor: Professor Thomas Bräunl

Autonomous Driving

The Renewable Energy Vehicle (REV) Project at the University of Western Australia conducts research into electric vehicles, vehicle automation and autonomous driving systems. Recent projects include the development of an Autonomous Formula-SAE Electric car. This vehicle is an open-wheeled, electric drive race car, with electronic drive-by-wire and electromechanical brake/steering actuation. The vehicle serves as a compact, flexible test-bed for sensor testing and the development of autonomous driving algorithms. The group's current focus is the high-level automation of a passenger shuttle bus, using an electric drive-by-wire platform from French bus manufacturer Ligier, but with our own navigation system. The shuttle will operate as a self-driving people mover on campus shuttle and will be flexible enough to dynamically plan its route. All sensory and navigation processing is on-board; there will be no dependence on cellular networks or other high-bandwidth communication systems or remote servers.

Development of Level 3+ Autonomous Driving Systems (ADS) presents a significant risk to both people and infrastructure due to the requirement for complex, software driven electromechanical systems to now provide safe driving behaviour under normal conditions. Indeed, whilst Autonomous Vehicles have been heralded with promises of improved traffic safety and lower collision rates, current technology may not offer these advantages and significant progress is required in the realms of safety and reliability, with disengagement of autonomous systems, requiring resumption of manual control to achieve safety still relatively common. With technologies improving rapidly, the situation is expected to improve. However, like the critical systems used for aeronautical control, there is significant room for improvement of the processes used to assure safe performance.

This year, our work with the Formula-SAE car involves replacement of the braking system with a fail-safe pneumatic actuation system, controlled by a new automotive grade safety system. This work has been sponsored by SMC Pneumatics and will significantly improve the safety and performance of the vehicle. In the case of the nUWAy shuttle bus, current work involves assessment and augmentation of the bus's existing sensing, control and safety systems to allow us to achieve our target of intelligent autonomous driving.

Zhihui (Eric) Lai

Supervisor: Professor Thomas Bräunl

End-to-End AI Methods in Autonomous Driving

The interest in autonomous vehicles has increased exponentially in recent years. While mediated perceptron (traditional approach) is a proven autonomous driving technology, end-to-end learning approach has become popular because of its potential to reduce time, human and monetary costs. However, despite the emergence of many end-to-end approaches in recent years, none of the end-to-end approaches can cope with most traffic scenarios as well as the traditional approaches. These methods can either only work in specific weather or in specific regions. At least four aims are to be achieved in this project—(1) Build an end-to-end neural network system that includes temporal and spatial information and outputs predicted trajectories using cameras, ego states, and a roadmap as inputs. This system needs to be able to cope with most complex traffic scenarios and can be continuously improved through online learning; (2) Add auxiliary outputs such as semantic segmentation, object detection, depth information, and motion detection to the model of (2) to enhance the interpretability of the model and make it easier to optimize; (3) Build an end-to-end neural network system that includes temporal and spatial information and outputs predicted trajectories using LIDARs, ego states, and a roadmap as inputs. This system needs to be able to cope with simple traffic scenarios and be able to continuously improve through online learning; and (4) Fuse the system of (2) and (3) for redundancy, the fused system should have higher accuracy and stability.

Kieran Quirke-Brown

Supervisor: Professor Thomas Bräunl

Automated Obstacle Avoidance

Developments in driving automation have come a long way in the past 10 years as we see a wider range of companies and universities tackling the problems within the autonomous driving space. Much of the current research is looking into dynamical obstacle avoidance in unknown scenarios and there have been a number of papers published around this. Many of the algorithms designed in this space, however, were designed for smaller robots which have different restrictions and interactions. The focus of this research is to look at dynamic obstacle avoidance for larger vehicles like the nUWAy shuttle bus in different environments. Additionally, many of the algorithms focus on getting to the destination as quick as possible and don't consider dynamic changes over time. To improve existing systems, I will be looking at designing a system that considers both static and dynamic obstacles and makes the best decisions based on user comfort and safety with time being a secondary consideration. The system will also make evaluations on the current scenario, built based on sensor data, to make early predictions of future events and path plan accordingly. We currently have 2 buses, one on the roads in Eglinton, a suburb in the north of Perth, and one for the UWA campus. It is important to understand how these interactions differ and how they are the same and develop a system that can handle the changing environment.

Machiel van der Stelt

Supervisor: Professor Thomas Bräunl

Road Safety

This research revolves around bicycle Road Safety with 3D solution systems and an Autonomous Bus (AB). The project is in cooperation with the Western Australian Centre for Road Safety Research based at the School of Psychology Science at UWA.

The first study of a total of three studies involves the creation of a novel method to accurately measure the distance of the bicycle to a reference point and the functional location of the bicycle within a Virtual Reality (VR) 3D environment. In effect, two novel methods will be compared in respect to accurate and automatic recording of roadside curb deviation and route-location data of a cyclist in a VR simulator environment.

The second study will use an AB to scan the surroundings with fitted Lidar sensors to detect objects and persons in close proximity. This study will consist of two stages. The first stage consists of a software simulation, where the AB scans for objects and persons on the UWA campus and drives according to the perceived situation.

The third study will evolve around the AB and the intercommunication between Vulnerable Road Users (VRU's) and a AB in different road settings to improve Road Environments with AB's and VRU's.

Current **Masters Research**

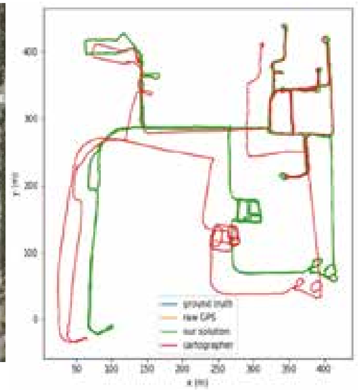
Kyle Carvalho

Supervisor: Professor Thomas Bräunl

Autonomous Vehicle Control using Global Navigation Satellite Systems

The aim of this research is to produce a robust LiDAR aided GPS localisation for autonomous ground vehicles. The system takes only raw 3D point cloud data from LiDAR, and position data from GPS sensor. The position data from GPS is pre-integrated with IMU and is acquired at a fix rate. The system uses an adapted Cartographer for lidar based localisation and a correction program using independently developed software. In the pre-processing stage, the point cloud from LiDAR is filtered to remove scans from the vehicle body and the ground surface. Then all point clouds will be projected into a 2D scan for processing. Upon receiving the laser scan data, a hit rate will be calculated by matching the laser scan and the occupancy grid from the map. A correction offset on both translation and rotation will be evaluated if the original hit rate is below a certain threshold. This correction offset will then be applied to update the transform for the final localisation result.

Seen below is a comparison of a LIDAR map vs a real map of the UWA Shenton Park campus using Cartographer.



Yuchen Du

Supervisor: Professor Thomas Bräunl

Lidar-based Autonomous Driving

With the development of autonomous driving technology, an increasing number of vehicles with autonomy capability are appearing in the unstructured environment (e.g. university campus, mining, agriculture and forestry and defense areas). Different scenarios need the vehicle to perform different tasks, thus normally raise different requirements for vehicle functions. For example, a passenger-carrying vehicle in the campus should avoid collisions while not making sudden changes in its movements at the same time. A surveillance vehicle operating in a large defense sector has to run at a high speed to cover the full area but pay less attention to the comfort.

The first part of the thesis focuses on two self-developed autonomous vehicles, the nUWAy shuttle bus and the ASV (Autonomous Security Vehicle), which are appropriate solutions to the scenarios mentioned above. More specifically, the thesis proposes the software architecture for the shuttle bus so that it is able to handle the task of operating in the campus environment. For the ASV, due to the remote operation in the defense sector, it needs to drive at a high speed in operation and have the autonomous charging function after the mission. Proper solutions to these two requirements are also proposed in the thesis.

The second part of the thesis reviews and investigates SLAM technologies. Simultaneous localization and mapping (SLAM) is the technology by which autonomous vehicles are able to gradually create a map using onboard sensors, and achieve self-localization concurrently under unknown pose and the environment. Two typical SLAM frameworks, Lego-Loam and LIO-SAM, are compared on KITTI dataset in this thesis, demonstrating the difference between pose graph and factor graph against the backend optimization performance. Also, our self-developed sensor pack with LIO-SAM is tested in tunnels, demonstrating its promising performance in GPS-denied environment e.g. mining sites.

Master of Professional Engineering & B.Phil (Hons) Dissertations

Alishan Aziz

Supervisor: Professor Thomas Bräunl

Automated Height and Banking Control of Hydrofoil Ski

Riding jet skis has become one of the most popular means of recreation particularly in coastal cities like Perth. Most people are out on lakes, rivers, or even the ocean, riding skis especially over the weekends. However, like most crafts, these skis consume fossil fuels and subsequently waste most of their energy crashing against waves. Even in skis that are electric, most of the added mass in batteries exists solely to compensate the energy lost crashing against waves.

A new class of electric hydrofoil skis are now in development across the world that overcome both these issues when 'foiling' – the state in which the craft is lifted above water surface. Additional advantages of hydrofoil skis include longer riding range and time, effective energy consumption, and fewer batteries required in-craft compared to traditional electric skis. The University of Western Australia's (UWA) Renewable Energy Vehicle (REV) Project has a hydrofoil ski in development.

The skillsets required to ride a hydrofoil are different from those required for a traditional ski. In crude sense, required skills can be considered an amalgamation of motorcycle skills and traditional ski skills. To make hydrofoil skis more accessible to the public, embedded control systems must take over the complex tasks of attitude control and banking based on sensor feedback of height, pitch, roll, and yaw. This project involved developing control algorithms implemented in the central microcontroller to effectively address these control requirements.

PID control implementation is worked on for controlling servo motors adjusting the hydrofoil aileron banking angle (producing lift and banking) as well as adjusting pulse-width modulation (PWM) that controlled speed of motors to achieve differential speeds for turning when craft is not foiling at low speeds.

Complementary work done in successful pursuit of this project include designing of Controller-Area Network (CAN) architecture and Graphical User Interface (GUI) to display and log relevant information of hydrofoil performance.

Xiaochen Bi

Supervisor: Professor Thomas Bräunl

Pedestrian detection on autonomous bus

Yolo is the fastest object detection model until now. It has already been used in different areas. It is also useful for the pedestrian detection on autonomous vehicles, because with this technique the vehicle can know pedestrians in advance and react in time. In REV lab we have a driving simulation platform based on Carla which can simulate an autonomous bus driving around uni. In the simulated world, there are no pedestrians on the campus, but in real life, there are always students walking around on campus. Adding pedestrians to the simulation environment can improve the authenticity of the simulation environment, and we also add pedestrian detection to the simulation system.

This thesis is about how to use yolov3 on UWA autonomous bus simulation platform based on Carla to realise pedestrian detection and judge the approximate distance between pedestrians and vehicles, so that the autonomous bus can determine whether it is necessary to avoid pedestrians in advance. Basically, the most important part is a ros node called darknet_ros. This ros node allows us to apply models trained by us. In the research, a model which can detect 3D model people is trained. This process can be summarized as label pictures, organize dataset, modify config file, train model. This model can detect pedestrians and their head. By the size of peoples head, we can estimate the distance between people and vehicles because the distance is inversely proportional to the size in image. The next step of the research is about point cloud, so that ridar and camera can work together.

Jai Castle

Supervisor: Professor Thomas Bräunl

Designing an autonomous navigation system for an autonomous shuttle bus with real-time obstacle avoidance

The fully electric nUWAy shuttle bus was purchased with no preexisting software, in order to develop an autonomous driving software system for operation on the university campus. It is equipped with several sensors, including LiDAR sensors for mapping the environment and detecting obstacles to avoid collisions. However, previous work on the nUWAy vehicle enabled rudimentary self-driving capabilities, but no real-time obstacle avoidance. This project investigates how enhanced software navigation systems allow for safe and effective operation alongside pedestrians, cyclists, and vehicles. The main objectives were to achieve a flexible and modular system with real-time obstacle avoidance, that facilitates autonomous operation. While the literature presents a navigation architecture with dynamic obstacle avoidance in small robots, little work has been done to verify these approaches in large vehicles and complex environments.

A redesigned architecture was determined to be the most effective, after evaluating the alternatives. The desired high-level behaviours were planned to be modular and support the set of required features. Additional software was also developed to support navigation through waypoints sequences and improve driving dynamics. Finally, testing, evaluation and subsequent adjustments to the system were completed. There were promising results during testing on the university campus. However, the path following method used was difficult to fine-tune and could be replaced with a bespoke solution. The system avoided collisions, despite the often unpredictable movements of pedestrians, cyclists and other vehicles. Notably, the general cooperation of other pathway users with the vehicle acted to reduce the amount of evasive action required. These results suggest that navigation systems and architectures designed for small-scale simple environments can be applied to larger, more complex environments. Real-time obstacle avoidance was achieved, without consideration of obstacle trajectories, suggesting that complex object tracking methods are not always required. Additionally, these techniques could be extended to support autonomous driving on road networks, including in complex situations. Future work could involve the development of an optimised path following system, and support for hailing a vehicle, and developing a road-going version for commercial vehicles.

Jason Chu

Supervisor: Professor Thomas Bräunl

Safety in Software: An Autonomous Vehicle Approach

Following advancements in new technology for autonomy in driving, several vehicles can now achieve the status of self-driving or autonomous driving. The removal of human interventions in driving changes the economy of safety to consider during vehicular use, especially for public transport and matters involving pedestrians and public passengers. The shift in safety concerns involving driving decisions that are now to be dictated by computers and sensors have been rarely addressed, and now, in the absence of educating human drivers, new precautions must be undertaken to increase the level of safety concerning both passengers and pedestrians. The University of Western Australia's nUWAy shuttle bus is a vehicle that has been undertaking autonomous driving research and development. The singular safety system of a digital Light Detection and Ranging Sensors (LiDAR) emergency stop curtain remains insufficient for public use. This research aims to discuss and create new solutions for safety applications on the nUWAy shuttle bus. It discusses vehicle safety concepts that are important to autonomy, hazard prevention, passenger, and pedestrian safety, and focus on software safety practices. It follows the implementation and limitations of the onboard SICK Safety Programmable Logic Controller (PLC) and potential improvements, and how this can be provided on a software level. Alternative software features and methods have been taken to increase degrees of safety through the shuttle's Robot Operating System (ROS) framework and examines how the data passthrough of the system can be harnessed to improve status feedback for both development and public use. An onboard watchdog software node and system is under development for use on the nUWAy shuttle bus, covering multiple points of failure experienced during autonomous testing during the system's continued development.

Matthew Connell

Supervisor: Professor Thomas Bräunl

Autonomous Solar Powered Boat (SAPB)

Since 2017 The University of Western Australia has pursued the goal of creating an autonomously guided, near-unlimited range, surface vehicle capable of circumnavigating Rottnest Island. Significant work was completed in 2020 to re-design the hull and overhaul/upgrade all control systems and wiring, the new vessel, is now known as the Solar Powered Autonomous Boat, (SAPB).

Due to its robust nature, low running costs and flexible payload carrying capacity the SAPB, received genuine interest from external parties and departments within the University, to autonomously collect survey data for research and commercial purposes. After initial attempts at using/testing the SPAB, it became clear that the current vessel did not have a supporting network of hardware that allowed for a timely and consistent deployment.

This thesis takes the perspective of a Mechanical Engineer, in upgrading the SPAB and designing the subsystems that are needed to make the SPAB easily and readily deployable to prepare it for use in the wider academic or commercial context.

The project method involved, assessing the current state of the SPAB to determine the areas of priority for upgrades and implement new features. Designs were created and implemented, using modern manufacturing techniques such as 3D CAD modelling, CNC Machining and 3D Printing.

The design process and implementation of notable upgrades will be described as follows, project status and review, design and construction of transport equipment, design and construction of a ground control station, upgrades to the radio communication system, integration of client sensors, creation of a user manual, testing and results, final assessment, and further work.

No matter how capable a project or product is, without the supporting network of hardware and a detail plan for using the vessel, it will not be capable of being readily tested and or used for the intended purpose. The new supporting hardware makes the SPAB readily deployable, it can now be used in any location, and be in the water ready for testing at a fraction of the time of previous iterations. The integration of sensors and testing shows that the SPAB is a capable platform to collect data for research purposes and is suitable for inter cohort collaboration and can be used by colleagues without a robotics or mechatronics background.

Thomas Copcutt

Supervisor: Professor Thomas Bräunl

Implementation of Visual SLAM for Autonomous Shuttle Bus

In this research a Visual SLAM solution with GPU utilisation is proposed for the nUWAy shuttle bus to replace the currently implemented LiDAR based SLAM solution. This follows from an underutilised GPU and issues of bottlenecking from the CPU experienced during execution of the bus's autonomous stack. Visual SLAM was chosen as it can make better use of the underutilised GPU than the LiDAR SLAM solution, which runs on CPU. Such work has promise for application in many other contexts on systems using heterogeneous CPU-GPU and System on Chip architectures.

Proven and mature Visual SLAM algorithms exist in prior research and shows potential for parallelisation of computation on the GPU. Adoption and modification of these implementations ensures an efficient base solution with minimal initial computational cost. Key areas of the SLAM algorithm are identified which have both high parallelisation potential and a significant compute expense. These tasks will be focused on for execution on the GPU.

The success of this project will ultimately be determined by the ability to lower the load on the CPU, as this result will successfully reduce the extent of bottlenecking of the system. It's unknown whether computation on the GPU in these scenarios will improve compute times so such metrics will also be assessed.

The performance will be reported based on:

a. Known to work ORB-SLAM examples, processed on a high-powered graphics workstation.
b. Pre-recorded data of the bus in a typical environment, processed on a high-powered graphics workstation.
c. Pre-recorded data of the bus in a typical environment, processed on the bus's internal systems.
d. Live data from bus cameras processed on the bus's internal systems.

These datasets will be compared to both an unmodified visual SLAM solution with which processing is done on CPU, as well as the current LiDAR based SLAM solution to determine a final feasibility of implementing the change.

Lemar Haddad

Supervisor: Professor Thomas Bräunl

Increasing Reliability of an Autonomous Vehicle Stack in Robot Operating System 2

The University of Western Australia (UWA) acquired an autonomous shuttle bus, nUWAy, in 2020. Students combined open-source software with their own software to build an autonomous stack, currently in the node-based Robot Operating System 2 (ROS2) platform. The current aim of nUWAy is to provide a student-run service offering autonomous rides at UWA. The operators of the service are regular students who should not require any technical knowledge outside of basic training to run the drives. Though autonomous demonstrations have been completed successfully by technical students, there have been overwhelming instances where nUWAy has been unable to complete drives due to software instability issues. These issues require a technical knowledge of the stack to recover from, taking technical students up to 30 minutes to recover to a driveable state. If left unresolved, these issues will arise in regular drives where non-technical operators will be forced to engage technical resources to recover the software stack, resulting in unpleasant experiences for passengers and operators. This project aims to improve high-level reliability of the software stack, so that it is more usable by non-technical operators.

In a 3-week period, autonomous software issues and failures were tracked and categorised within a spreadsheet, to identify areas of improvement. In over 56 hours of testing, it was found that the localisation and mapping tool, SLAM Toolbox, was responsible for 58.7% of all failures experienced. Furthermore, 98.3% of SLAM Toolbox failures were major and required a restart of the software stack. A process of parameter tuning, different installation methods and versions of SLAM Toolbox has yielded varying degrees of success, but the issues mainly impacting the localisation of the vehicle on a map were unable to be resolved. A promising solution currently in trial is a hybrid of SLAM Toolbox for mapping and AMCL (Adaptive Monte-Carlo Localizer) for localisation, eliminating major failures caused by SLAM Toolbox, but still requires some tuning to improve localisation accuracy. For improved usability by non-technical operators, a software monitor is in development, which aims to control the start-up of the system, monitoring, and recovery of critical nodes in the autonomous stack. This aims to ensure that the stack always starts correctly and can recover from most node-related errors which could appear at runtime, so that non-technical operators will not have to have any knowledge about the software stack to run the autonomous bus.

Kai Han

Supervisor: Professor Thomas Bräunl

Hydrofoil Jet Ski Project: Electronics System Optimisation, Integration, and Design

The REV Hydrofoil Jet ski project aims to develop the world first electric hydrofoil Personal Watercraft (PWC). The hydrofoil variant is the second iteration of the electrification of PWC, which improves upon its power efficiency by reducing the drag, and provides greater traveling velocity through the utilisation of hydrofoil technology. To achieve minimum drag and maximum lift, the fully-submerged Hydrofoil design was chosen. However, in comparison with the surface-piercing hydrofoil, the design lacks inherent stability. Hence, an autonomous balance control system is needed, in order to create a consumer-friendly PWC.

This thesis/seminar explores the optimisation, integration, and design of the complimenting circuitry of the microcomputer, which issues commands to balance the jet-ski and to log the necessary data. Prior to the commencement of the thesis, replacement and redesign of the electronics system was needed due to the limitation of the previous controller. For replacement, the team proposed to use Beaglebone Blue, a single board microcomputer platform running on Linux Kernel.

With respect to the hardware integration design, the current daughterboard with mounted commercial modules (SOIC-8 boards), which facilitates interactions between the microcomputer and the rest of the electronics, must be tested and further developed. In order to optimise the circuitry, electronics on the commercial modules could be integrated with the daughterboard, forming a single, 2-sided PCB. This would decrease the dependency of the project on commercial products, provide space for future add-ons, and reduce the overall cost of the jet ski. The result also led to the modification of the current daughterboard, which is used for rapid prototyping only.

With respect to the software integration, each module was first tested in isolation using a microcontroller, before it was included in the new design. The purpose is to compliment and justify the hardware optimisation and integration. There are in total 3 commercial modules and 1 depth sensor, which were considered in the process. One of the key focuses is the exploration of the ADC to I2C converter chip, which possesses interrupt capability. This function and its interaction with the Linux based microcomputer were explored, in order to optimise the time it takes to acquire sensory data during each control loop.

Future development on this project would include the production of the new daughterboard (PCBA), and the integration of the software solution of the ADC to I2C converter chip into the main program.

Minglong He

Supervisor: Professor Thomas Bräunl

Remote Operation of a Thickness Testing / Carry Back Measurement Mobile Unit

The main of the project is to perform thickness testing by applying autonomous testing methods to replace manual interaction. This will enable specific measuring points to be collected autonomously, remotely, and securely. By applying an autonomous testing method to perform the thickness testing, this will result in a lower cost, increase the accuracy of thickness testing, and reduced processing time. This will help the end user to make a better-informed prediction of truck body floor lifespan and to make maintenance strategies quickly and precisely. This will take truck body inspections to the new level, making Austin Engineering the market leader due to this high-quality service. The project adopts the use of autonomous robot technology to take thickness measurements at various point on the truck body floor. This autonomous robot will make use of self-orientation functionality.

To ensure the robot can meet the objectives of the project with good performance and accurate path planning, the project process can be concluded into requirements analysis, robot model selection, designing and function testing. The most significant stage is designing stage which includes coding for navigation function and high-level design for whole system. The robot vehicle of "Turtlebot 3 Burger" is selected for this project. The Turtlebot 3 has a scalable structure, a lidar sensor for navigation, one single-board computer for raspberry pi, one OpenCr for controlling the DC motor.

Numerous lab tests were conducted to date for the robot vehicle navigation function regarding the initialization process, mapping process and pathing planning using different methods. The accuracy of environment mapping and path planning were tested. The key deliverables for this project are to hand over a high-level design of the testing system, the prototype of the robotic vehicle with navigation function, all corresponding codes/datasets and a user manual. A robot vehicle with the navigation function has been successfully developed and tested in the lab environment. The robot vehicle can move towards to each goal point in lab test accurately. The research has successfully yielded a high-level system design with the desired outcomes.

Zhihui Lai

Supervisor: Professor Thomas Bräunl

End-to-End learning: Autonomous driving system based on PilotNet

This thesis aims to continue the research of the ModelCar-2 project and develop a more functional and reliable autonomous driving system utilizing deep learning. In the previous ModelCar-2 project, a fully end-to-end method that applies PilotNet neural network was developed, involving a current image as input (the dataset was collected by Lidar drive mode and preprocessed) and a steering command and speed as outputs. This method achieved the Lidar-based methods' performance while presenting advantages like higher and consistent frame rate and low cost. However, a significant drawback was no past information, imposing an error-sensitive performance, especially in high speed and complex environments. Spurred by this deficiency, this thesis introduces two new models: CNN + LSTM and 3DCNN, aiming for autonomous driving in high-speed and complex environments. This is because in deep learning methods, despite the current image being damaged by external factors like vibrations and obstructions on the camera, they can still exploit past images to produce the right steering decisions. Furthermore, deep learning can learn more complicated driving skills like recovering from failures and turning around.

While building these models, multiple influencing factors are discussed: memory capacity, dataset balance, TensorFlow version compatibility with Raspberry Pi, frame rate, and Raspberry Pi's computing power. The three experiments investigated in this thesis challenge the CNN + LSTM and 3DCNN model against the original PilotNet and Lidar models. The first one involves a maze map in the EyeSim simulator, which can run several models simultaneously and compare their speed, autonomy, and reliability. The second experiment considers the 4th floor of the EECE building, where the models circle within a rectangular area separately, and we compare their speed, reliability and autonomy. Finally, the third experiment is in the corridor of the CME building, where the models turn around in a narrow corridor separately, and we compare their speed, reliability and autonomy.

Fraser Loneragan

Supervisor: Professor Thomas Bräunl

Deep Learning for Mobile Robots

In 2022, driverless cars are still not available to the public. Most, production cars today however come with level 1 and level 2 Advanced Driver Assistance Systems (ADAS). These include level 1 ADAS such as adaptive cruise control, emergency brake assistance and lane keeping and level 2 ADAS such as highway assist, autonomous obstacle avoidance and autonomous parking. One of the primary benefits of autonomous vehicles is their potential to stop or reduce the number of vehicle accidents caused by human error, however the development of driverless car software is often impeded by cost, safety, laws, and regulations. Mobile robots are not constrained in such ways and therefore are well suited to develop and test driverless car software. Artificial Intelligence (AI), Machine Learning (ML) and Deep Learning (DL) are often used in ADAS but can be very computationally expensive.

Recently technical developments have allowed for this type of software to run in real time on single board computers (SBC) such as the Raspberry Pi 4 or 3B. Today, there are even some SBCs such as the Jetson Nano which come with onboard GPU cores. GPUs are often used in the training and inferencing of DL models. This is due to the increase in parallel computing that can be achieved by a GPU (which often consist of 100's or even 1000's of cores) compared with a CPU (which often consist of 4 plus cores).

The aim of this project is to expand upon deep learning and autonomous driving algorithms built by past UWA students with a Jetson Nano instead of a Raspberry Pi. The new system retains the same EyeBot IO board but instead uses the Jetson Nano for computation rather than a Pi. The Jetson Nano can run more complex DL neural networks at higher frame rates than a Pi due to the utilization of GPU cores on the Jetson Nano. The DL models used in this project include an end-to-end lane keeping model using PilotNet, traffic sign detection model using MobileNets and a Convolutional Neural Network (CNN) model to detect the speed limits posted on speed limit signs.

The project was successful at navigating the track and detecting and reacting to traffic signs at an acceptable speed (10-20 Hz). Furthermore, this project will serve as a basis for future students considering using a Jetson Nano for their EyeBot projects, which previously were only able to run on a Pi.

Nyi Myo Maung

Supervisor: Professor Thomas Bräunl

Intelligent Industrial Robot Control for Nachi Robot

Autonomous driving is one of the most interested topic among scholars and researchers in the recent years. Currently, there are two main approaches in development of autonomous vehicles, modular hand-crated method and end-to-end method. Modular method requires large amount of expensive sensory devices like proximity sensors and lidars along with complex commands whereas end-to-end method mainly depends on cameras and the neural network which make its own decision based on training data without requiring explicit commands.

The project will be carried out on a heavily modified RC car called ModelCar, which is equipped with a lidar scanner, a front-facing wide-angle camera and a Raspberry Pi4 running UWA developed RoBIOS software. Developers of ModelCar aim to demonstrate the effectiveness of a camera based end-to-end system that can match the performance of the more complex and expensive lidar based system.

The aim of this research project is to continue the previous research done on ModelCar and further develop an improved low-cost end-to-end driving model that could outperform the original one. Since the previous versions of ModelCar is trained based on Nvidia Pilot Net system where a single image frame is used for deciding the output, the proposed model is to test out and develop time-series based end-to-end methods which uses historical images of training data to further enhance the autonomous driving system. Comparisons will be made between previous attempts on the model and provide an insight and validity of the proposed model.

Simulations has been done on UWA developed EyeSim platform to compare the original ModelCar model and the proposed model. In the ideal world of simulation, the proposed time series-based LSTM model, not only perform better than the original model, but it can also closely replicate the driving path of the training model. Real-world testing data are yet to follow the simulated results were in real-world settings, an intricate and well-trained model is required to cope with limitations brought up by low cost hardware and ever changing input data.

Hadi Navabi

Supervisor: Professor Thomas Bräunl

Intelligent Industrial Robot Control for Nachi Robot

Following the donation of the Nachi robotic manipulator ("Nachi" henceforth) to the University of Western Australia, a great prospect for educational and research activities for students, supervisors and lecturers were created. The Nachi robotics manipulator, with a payload of 133 Kg, creates an esteemed distinction between UWA and competing universities, and if promoted correctly, could generate interest amongst students of Mechatronics, Robotics and Automation.

To provide accessibility and easability to the wide diversity of individuals that may be interested in working with Nachi, and due to their wide range of experiences coming from different scientific fields, industries, and backgrounds, and due to the current complexities surrounding the operation of Nachi, there is a clear need for a simple method of communication. There should be clear and well-defined solution for all individuals to be able complete their tasks easily and independently. Hence the birth of "Nachos".

Nachos, also known as NachiOS (Nachi Operation System), is a refined and simple to use interface software and packages. Its objectives are to bring together and link Nachi's internal functionalities into a formal and understandable user interface. It aims to provide assistance to all potential users and individuals of Nachi, regardless of their dissimilar set of expertise.

For its most basic functionality, Nachos uses advance React frameworks to create a single-page multilayered User Interface. The page is divided into a grid of variable and adjustable sections that can dynamically be changed according to the use case and decision of the user. The sections are divided into the following functionalities. First section is an integration of Google's Blockly, to deliver Block Programming abilities into Nachos. These blocks are analysed using the proprietary internal packages and software, and eventually translate them into function calls that is understood by the Nachi's controller. This Nachi code is then displayed in one of the sections and is ready to be downloaded and copied to the controller. Additionally, Nachos will provide simulation on another section of the same page, which will be powered by Unity framework.

With the final release of Nachos, we are aiming to help out all students, lecturers and potential individuals that are interested to work with Nachi, to get a project started quickly and with ease, and to go through and complete the project independently.

Benn Ness

Supervisor: Professor Thomas Bräunl

Hydrofoil Raising and Lowering Mechanism Design and Analysis

The UWA Renewable Energy Vehicle Project focuses on revolutionising transport using zero emission vehicles powered by renewable energy sources. The Electric Hydrofoil Jet Ski is a project which improves upon the REV teams Electric jet ski, aiming to provide a jet ski which could glide through the water on two hydrofoils, providing a unique and enjoyable experience to the rider.

This thesis focuses on designing and implementing a raising and lowering mechanism for the middle and rear hydrofoils on the jet ski. As of right now the hydrofoils are manually raised and lowered. Several different options are explored to automate this process, with the main three being a rack and pinion system, a pulley system, and a folding system. These designs have been analysed using computer aided technology and then modelled to see how effective each design is and how it effects the motion and capabilities of the jet ski itself.

The proposed mechanism for the Jet Ski aims to minimise the current difficulties in loading and unloading the jet ski as well as making use in shallow water more feasible. This thesis also considers different approaches to the steering mechanism such as fixing it in place as well as having it return to centre in comparison to the typical jet ski steering system.

Vladimir Pavkov

Supervisor: Professor Thomas Bräunl

Design of Elevon Actuating and Hydrofoil Retraction Mechanisms for Electric Hydrofoil Jet Ski

Yolo is the fastest object detection model until now. In 2019 the UWA Renewable Energy Vehicle team helped develop a prototype electric hydrofoil jet ski, the first of its kind in the world. Since then, testing has been conducted, revealing the opportunity for a number of design improvements. This project will focus on the development of various mechanical improvements and the design processes involved.

The Ei-Foil is controlled and stabilised in part by the actuation of elevons located on the rear foil. The two servomotors that are responsible for the movement of these elevons have been affected by water damage issues during the testing process. To addressing these issues, a number of design concepts were generated. Inspiration was taken from the biomedical engineering industry with a Bowden cable driven actuation mechanism being designed. A simpler solution involving the implementation of a novel, more reliably waterproof servomotor is also considered. This solution involved the adapting the rear wing pod design to accommodate this bulkier servomotor.

The Ei-Foil is supported by two submerged hydrofoils attached to masts that extend from the Ei-Foil hull. For transportation over land, the Ei-foil must have its foils raised as to not impact the ground. Once the Ei-foil enters the water, the foils must be dropped. Currently, retraction and deployment of foils is done manually, with at least two people needed to comfortably carry out the process. One design objective was to implement a mechanical retraction device to eliminate the need for manual work. An additional objective is to allow for shallow water operation of the Ei-foil. If a rider were able to adjust the deployed depth of hydrofoils electrically while in a seated riding position, raising the foils would allow for shallow water operation. Previous work has been conducted on developing a mechanical retraction mechanism for the rear foil, resulting in a hydraulically powered folding design concept. This project aims to develop that work, as well as explore new alternatives. It will detail the entire design process of the developed solutions. The concepts that were generated are discussed and compared. Technical analysis is presented in showing how concept solutions were selected and how design parameters were determined. Finally, CAD models and engineering drawings of selected detail designs are presented, and recommendations are made.

Daniel Trang

Supervisor: Professor Thomas Bräunl

Analysis of Local Path Planners for Autonomous Driving

At the beginning of 2020, the Renewable Energy Vehicle (REV) team at the University of Western Australia (UWA) acquired a fully electric shuttle bus, later dubbed nUWAy. Upon purchase, all autonomous driving software used by the seller was erased from the vehicle's on-board computer.

The eventual goal of this entire project is to deploy nUWAy onto the UWA campus, where it would autonomously drive between the Reid Library and the Business School, acting as a bus for the general public. Path planning is one of the most critical elements of autonomous driving.

The university campus is a constantly changing dynamic environment; as such, the vehicle must navigate safely throughout the designated routes. Path planners are divided into a global planner and a local planner. The global planner requires a map of the environment to function, it is responsible for calculating the best route from one point to another, this is known as the global path. On the other hand, the local planner aims to generate new paths according to the vehicle's immediate environment, e.g. avoiding obstacles and undriveable terrain, while attempting to deviate from the global path as little as possible.

Currently, a global path planner has already been implemented on the shuttle. The purpose of this research is to analyse different local path planning algorithms which can be installed on nUWAy's infrastructure and make a detailed comparison via simulations to find out which one is the most suitable for a campus environment. The two that were researched and experimented were the Dynamic Window Approach (DWA) and the Timed Elastic Bands (TEB). nUWAy utilises the Robot Operating System (ROS), a framework designed for robotics development. ROS has libraries that implements these two algorithms. Testing was performed within the ROS stage simulation environment; both algorithms were tested in different scenarios and the behaviour of the vehicle was analysed.

Finally, the results of both algorithms were compared to determine whether or not they are suitable for use on the UWA campus.

Jairus Wong

Supervisor: Professor Thomas Bräunl

EyeSim Virtual Reality System for Robot Simulation

This project's main goal was to extend a virtual reality robot simulation program, EyesimVR. Eyesim itself is a computer-based robot simulation program, producing realistic simulations focusing on mobile robots. As a natural progression of Eyesim, a VR version, EyesimVR, was made for the Oculus family of VR headsets.

The aim of EyesimVR was to mimic the functionality of the desktop program, whilst utilising new features enabled by VR to allow for new modes of interaction with the robots within the simulation. However, when porting the program to VR, some pre-existing simulation features from the desktop program had to be removed or changed, and many other VR-based functionality have yet to be implemented.

As such, this project aims to provide upgrades to eyesimVR, which can be roughly split into three sections (with some overlap). Large system changes, which cover how the simulation program is run/customised by the user, VR specific changes, which cover changes relating to functionality specifically achievable through the use of VR, and small fixes, small changes which lesser impact the program.

A main milestone for the project was completing a large system change, which was the change in the programs simulation file intake and build process. The desktop Eyesim had an important feature, the ability to use custom scripts to control robots within the simulation. EyesimVR did not have this feature, forcing all robots to follow a small selection of pre-made programs. Although implementing the exact functionality from the desktop Eyesim is ideal, it was proving difficult, thus an alternative solution was implemented. This resulted in a few compromises, such as EyesimVR being built as multiple programs (each containing one simulation, rather than one program taking in multiple simulations), scripts/simulations had to be input before building, could not run c binaries, but crucially, allowed users to provide custom scripts.

Additionally, many VR specific features were implemented, a few examples include grabbing and throwing objects, toggle a help mode with popups showing button functionality, enabling robots to run their specified custom script, and enabling the left-hand command window to have much more control on the robots and simulation settings.

With the upgrades, EyesimVR is now able to simulate robots running custom programs, and is better utilising the VR technology. For future work, however, there are still many more possible upgrades that can be made to the program, for example, implementing the ideal system (single program, simulation files and custom c binaries loaded after program is built), or merging it with the newest version of Eyesim.

Zack Wong

Supervisor: Professor Thomas Bräunl

Multi-Sensor Data Fusion for Robust Urban Navigation

In autonomous vehicle applications, navigation data must reliable and accurate to facilitate safe driving. Global Navigation Satellite Systems (GNSS), Inertial Navigation Systems (INS), and Simultaneous Localisation and Mapping (SLAM) algorithms are widely employed within the field, however each of these approaches have drawbacks and deficiencies many of which are exacerbated by environmental factors. In particular, urban environments exhibit many features that can severely degrade the navigation performance of GNSS and SLAM based platforms.

This research demonstrates the shortcomings of various navigation sensors and proposes a framework to achieve accurate and reliable navigation through a loosely coupled fusion scheme using complementary GNSS, INS, and SLAM based localisation subsystems.

Experimentation has demonstrated that while Real Time Kinematic (RTK) assisted GNSS can provide highly accurate long-term positioning it is vulnerable to prolonged outages and performance degradation in heavily developed urban areas. GNSS is also prone to bias errors with can result in a significant offset between the sensor's reported and true positions. In contrast, INS solutions are largely immune to external environmental influences, however they suffer from integration drift, accumulating growing errors over time, making them unsuitable for long-term navigation. SLAM systems are effective at correcting for drift and bias errors in other sensors, but SLAM performance is heavily dependent on the presence of distinguishable features in the platform's surroundings. The fusion of sensor readings from a variety of complementary sensors presents a mechanism by which the drawbacks of individual sensors can be compensated for to maintain navigation performance.

The solution proposed by this research fuses GNSS, INS, and SLAM readings to form a robust navigation system optimised for urban navigation. It has been tested on the nUWAy shuttle bus, UWA's own experimental autonomous automotive vehicle, with experimental results demonstrating that fusing data from the diverse sensor suite onboard the platform successfully provides robust position and orientation tracking when navigating the challenging urban surrounds of the UWA campus.

Angelo Yu

Supervisor: Professor Thomas Bräunl

Deep Learning for Mobile Robots

This project aims to apply deep learning using images taken by cameras built into mobile robots to improve autonomous driving controls like enhance lane-detection and traffic sign recognition in a simulation environment. Past UWA Eyebot projects focused mainly on image processing techniques such as edge detection, and showed low accuracy in neural network driving.

However, literature states the limitations in image processing such as inaccuracy in detectinginconsistent lane markings, and suggests effectiveness in autonomous driving adaptation through neural network deep learning. The research aims build onto existing neural networks aided with image processing functions to achieve a fully autonomous mobile robot.

The method focuses on convolutional neural networks through python virtual environment with Tensorflow, OpenCV and dependencies to run data training algorithms. Data training process is implemented through Tensorflow models by obtaining processed images through OpenCV functions. Using Tensorflow training outputs, image classification of over 90% accuracy is seen using "Inception V3" and "PilotNet" convolutional neural network architectures. The trained model classifier is called upon, and can correctly manoeuvre along marked lanes in the virtual environment. Through testing and simulation, the mobile robot can also be adapted to a foreign environment with similar lane markings.

Major failure points of the robot include the inability to error correct once the robot has deviated from the lane markings, and certain locations of the road where low frequency of training data used. The solution retrains the model with an increased number of data points at the failure points to improve Tensorflow prediction accuracy.

The results show that the autonomous mobile robot is able to drive autonomously and follow lane markings. Troubles start to arise at points of intersections where there are low training data subsets. Future study should include implementing a smoother multi-input multi-output PIDdrive system that allows the mobile robot to travel accurately without jerky movement.

Zhewei Zhong

Supervisor: Dr. Kai Li Lim

EyeSim Cloud-based Monitoring and Smart Billing for Electric Vehicle Charging Stations

The REV Project operates Western Australia's first EV charging station network, which remains the only one fully operated by an academic institution in Australia. Having secured a grant from Oracle Cloud, we have provisioned an infrastructure and migrated our database onto it, with a web API to interface to its PostgreSQL back-ends. This project entails the delivery of an extension to the platform's functionality by introducing a billing system with visualizations that queries the database to inform EV users of their charging usages. This includes the design and deployment of a front-end web portal (user interface) and billing documents, in addition to interfacing with back-ends and payment gateways. The main language used in writing this project is React.js, which is a declarative, efficient, and flexible JavaScript library for building user interfaces, and allows programmers to compose complex UIs from small and isolated pieces of code called "components".

Specifically, Cube.js platform has been adopted, acting as a data access layer, it was designed to work with all SQL-enabled data sources, and has the necessary infrastructure and features to implement efficient data modelling, access control, and performance optimizations. In this project, Cube.js has been connected to PostgreSQL database, by SQL queries and data manipulation, Cube.js could visualize the dc and ac charging stations about who has used them, how long they've been used, how much energy supplied and how much bill to pay etc. giving a whole picture to the customers and owners of the charging stations, which helps them better identify the trends, patterns and outliers so as to gain insight into vast amounts of data. So that for example customers could choose a less used charging stations to avoid clash, and owners could better manage the charging network.

The dashboard is the user interface. There is a google map showing all the stations, when the users select one station, all the bar charts, pie charts, tables will change to be the visualization of this station, the users can also specify the time range they want to view. The combination of graph and table could provide both intuitive and precise information to the users.

The whole project has been stored in an ubuntu virtual machine instance of Oracle Cloud, so maintainers could modify the functionality or appearance of the website in any computer afterwards, besides, React.js itself is more maintainable than plain JavaScript, which makes the project easier to be maintained in the long run.

THE UNIVERSITY OF WESTERN AUSTRALIA

Computational Intelligence
Information Processing Systems
School of Engineering

The University of Western Australia
M018, Perth WA 6009 Australia
Tel: +61 8 6488 1763
Email: rob@roblab.org