INTELLIGENT TRANSPORTATION SYSTEMS - ACFR

THE UNIVERSITY OF SYDNEY

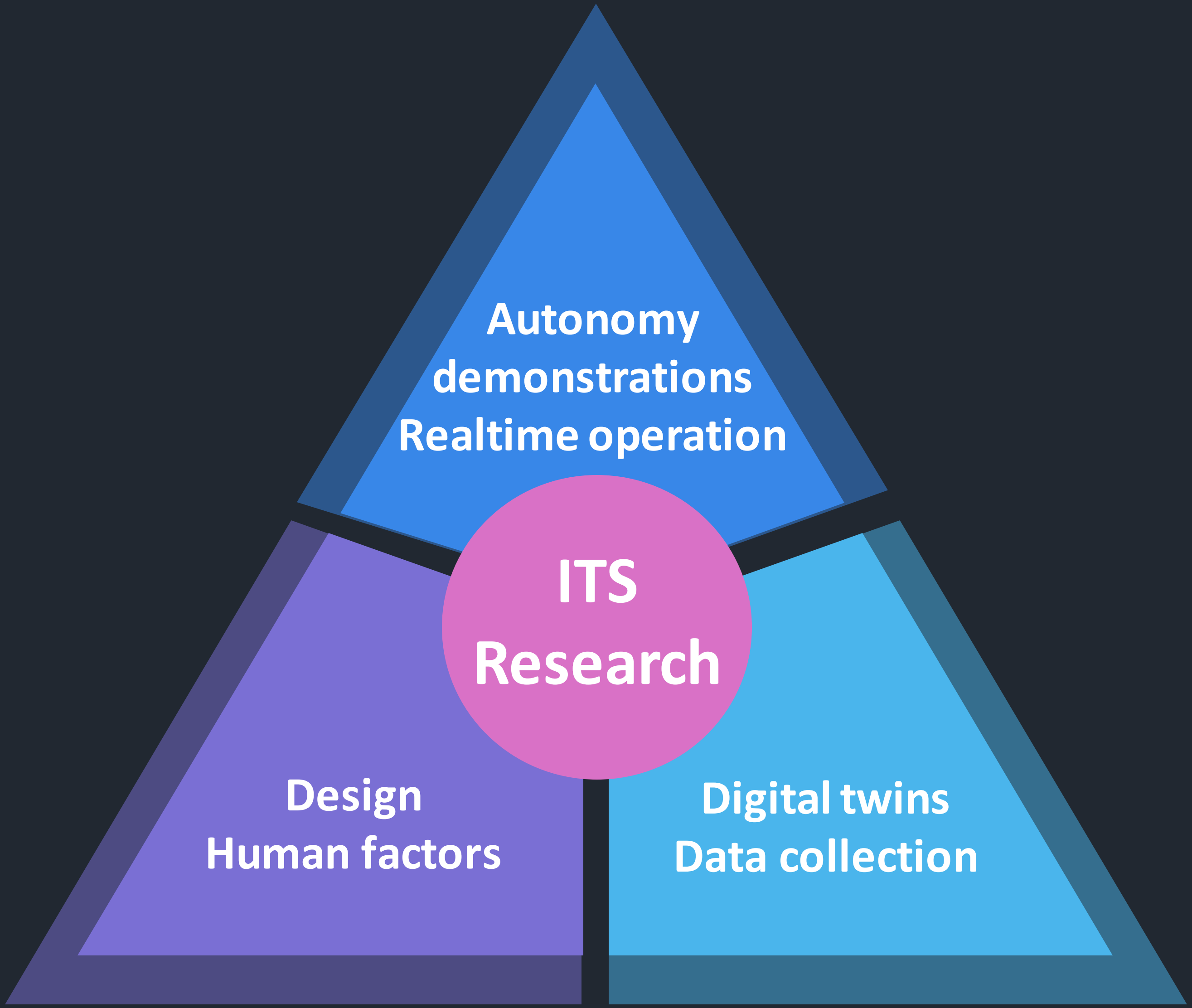
Australian Centre for Field Robotics

Stewart Worrall

PLATFORMS SUPPORTING RESEARCH AIMS

- Autonomous driving in urban areas
- Understanding the benefits of cooperation in ITS
- Collecting and publishing useful datasets
- Digital twins and human factors

OUR RESEARCH



LABORATORY AND EQUIPMENT

Hardware

2 Electric Vehicles with AV sensors
1 urban vehicle with AV sensors
2 Intelligent Roadside units
VR headsets

ROS1 – THE EARLY YEARS

video

MAIN CHALLENGES

- First 'robot' in the ACFR that has someone sitting in it, and must interact with other people and vehicles from the general public
  - Vehicle is road registered to operate autonomously under ODD
  - Required approval from NSW minister of transport
  - Significant amount of documentation/approvals/safety assurance working groups/etc.

BACKGROUND

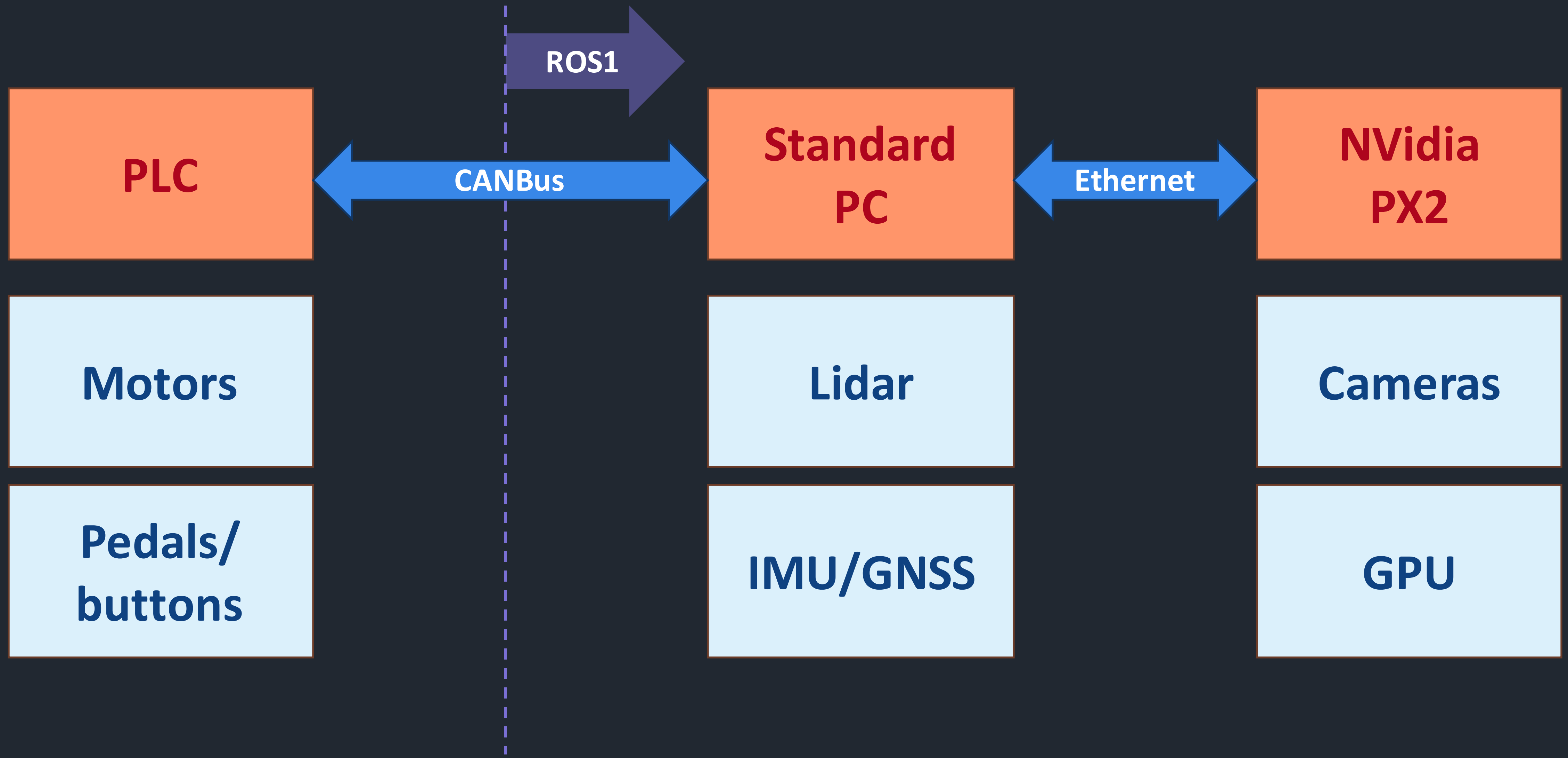
- Built by Applied EV in 2016 in consultation with the ACFR ITS team
- Delivered early 2017 with hub motors, motor controllers, PLC, PDM, hardware sensors (throttle, brake, steering)
- Retrofitted by ACFR ITS team to add compute, perception sensing, networking
- Used for data collection and autonomous driving projects through 2022

VEHICLE SPECIFICATIONS

There are two EVs, both have the following specifications:

- 1x SOK 48V DC LiFePO4 battery (16x 100Ah cells)
- 4x direct-drive hub motors (1000W each at front, 1500W each at rear)
- 4x Sevcon Gen4 motor controllers
- Maximum speed 40km/h
- Hydraulic rear wheel disc brakes
- Regenerative braking
- Cable operated park brake
- Hardware interlocks (seat switches and lap seat belt switches)
- 2400 x 1300 x 1600mm and ~500kg with two occupants

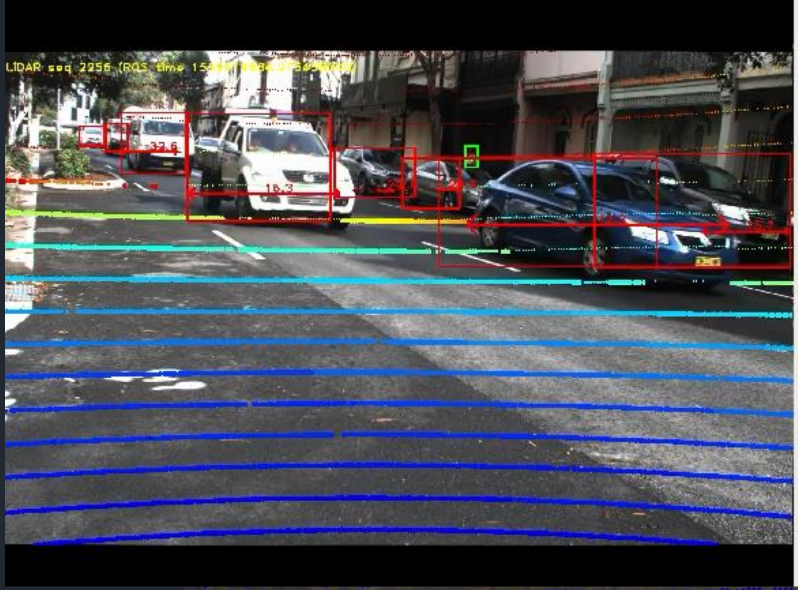
VERSION 1 – 'ROS'IFICATION

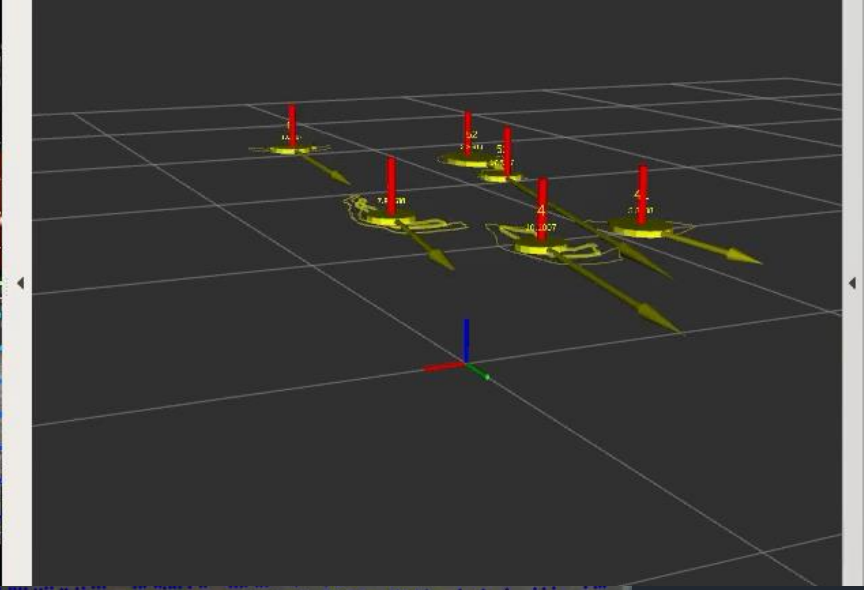


Control Architecture

- PLC generates commands to motor controllers, actuators
- **State machine in PLC determines which inputs to listen to**
  - Manual operation: driver inputs
  - Autonomous operation: commands from autonomy stack via CANOpen
- E-stop wired into PLC
- Brake pedal operation returns PLC to manual mode
- In autonomous mode, PLC automatically applies footbrake when stationary

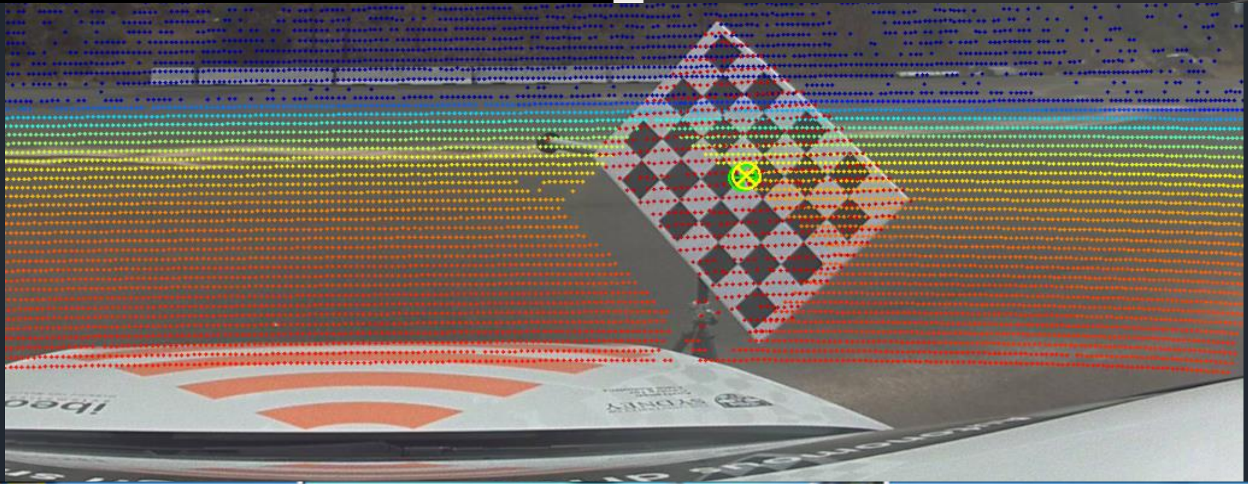
CAMERA-LIDAR PERCEPTION



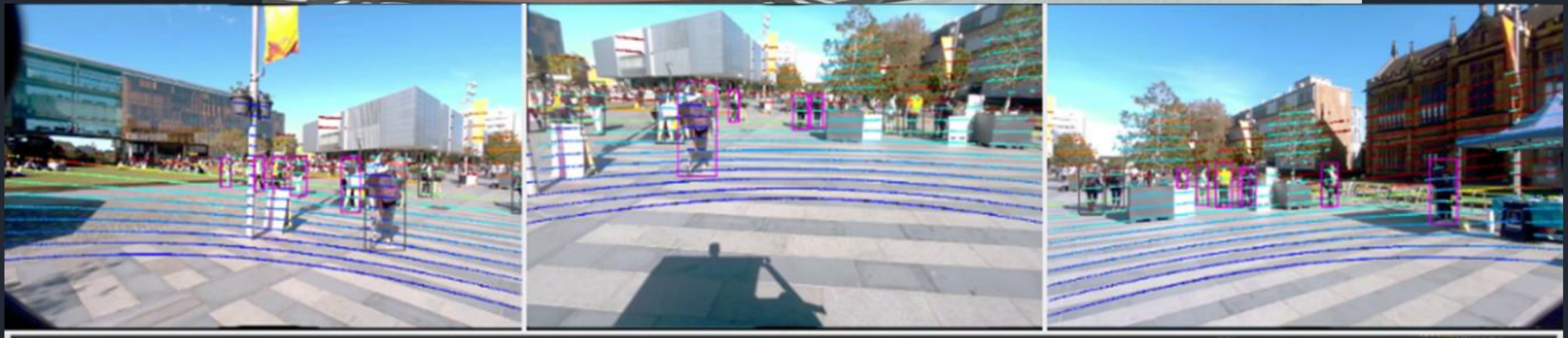


Camera detector

Lidar fusion



Multi-sensor fusion



Verma, S., Berrio, J. S., Worrall, S., and Nebot, E. (2019). Automatic extrinsic calibration between a camera and a 3d lidar using 3d point and plane correspondences. In IEEE Intelligent Transportation Systems Conference - ITSC 2019.

Tsai, D., Worrall, S., Shan, M., Lohr, A., & Nebot, E. (2021, September). Optimising the selection of samples for robust lidar camera calibration. In *2021 IEEE International Intelligent Transportation Systems Conference (ITSC)* (pp. 2631-2638). IEEE.

VERSION 1 – 'ROS'IFICATION PROJECT PHASES

The three-year project was broken into three phases. Each phase built on previous work with **increasing complexity**:

- **Higher speed**
- **Higher density pedestrians/vehicles**
- **Longer routes**
- **Integration of new technology**

PROJECT
PHASE 1

Low density, urban/pedestrian environment

- 250 metre loop
- 12km/h
- University roads
- V2V/V2I demonstrations
- Low density pedestrian context

Demonstration of Autonomous Transportation on Demand

Sydney University
October 2020

ACFR AUSTRALIAN CENTRE FOR FIELD ROBOTICS

NSW GOVERNMENT | Transport for NSW

THE UNIVERSITY OF SYDNEY

iMOVECRC.com

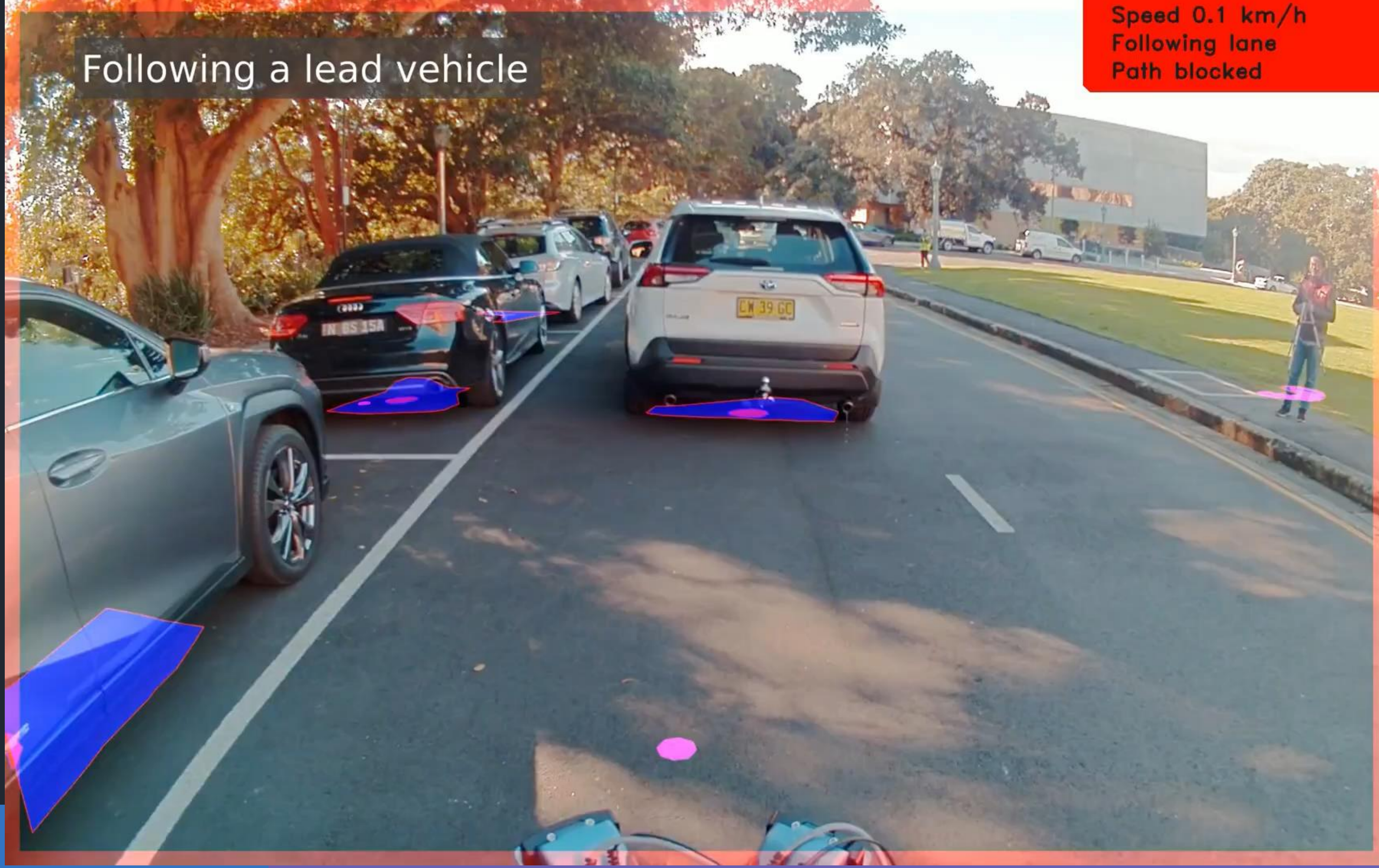
Pedestrian Interactions

Shared spaces

- Navigation around pedestrians
- Detection
- Tracking pedestrians
- Understanding intentions

PROJECT PHASE 2

Mixture of low-speed urban/ pedestrian environment



- 900 metre loop
- 10km/h shared space, 20km/h public roads
- University roads/spaces
- V2V/V2I demonstrations

Pedestrian Interactions

Shared spaces

- Navigation around pedestrians

Main tasks

- Detection
- Tracking pedestrians
- Understanding intentions
- Safe, intuitive vehicle path planning

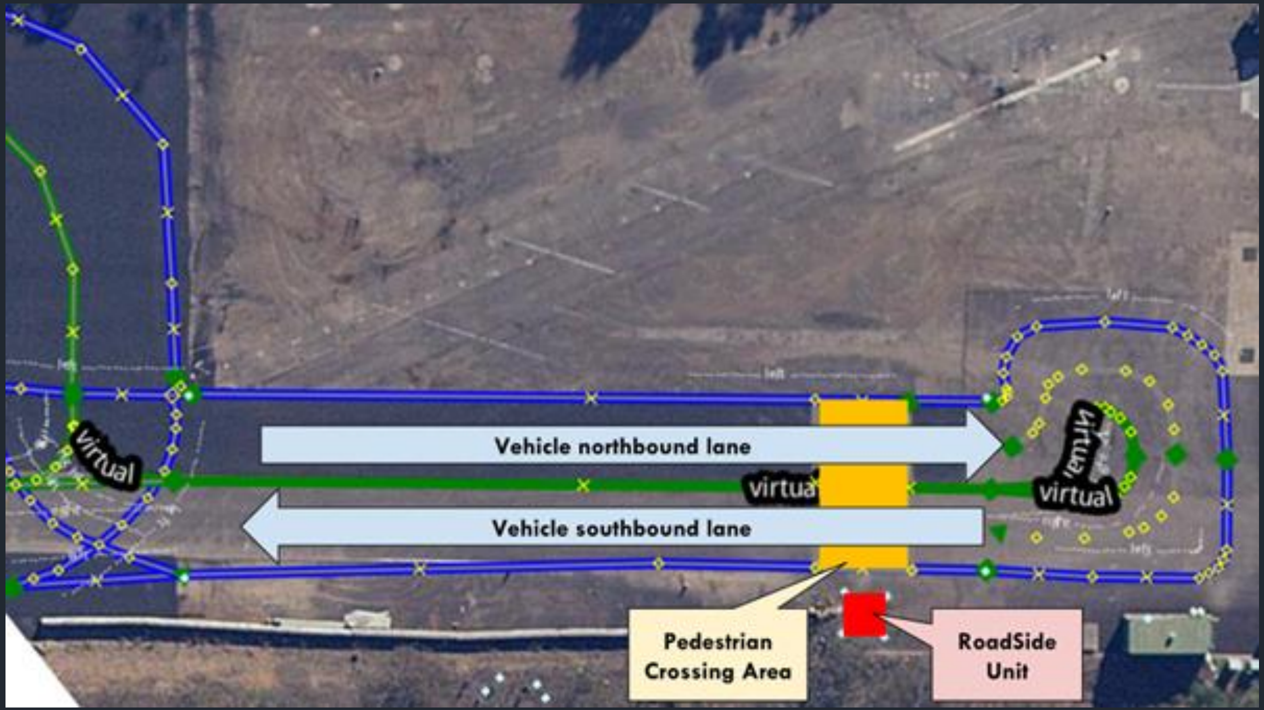
PROJECT
PHASE 3

Mixture of medium-speed urban/
pedestrian environment

- 700 metre loop
- 25km/h on-road, 10km/h shared spaces
- Public roads in Chippendale
- Live traffic
- Intersections, roundabout, traffic light (human in the loop)
- Public roads open to traffic.

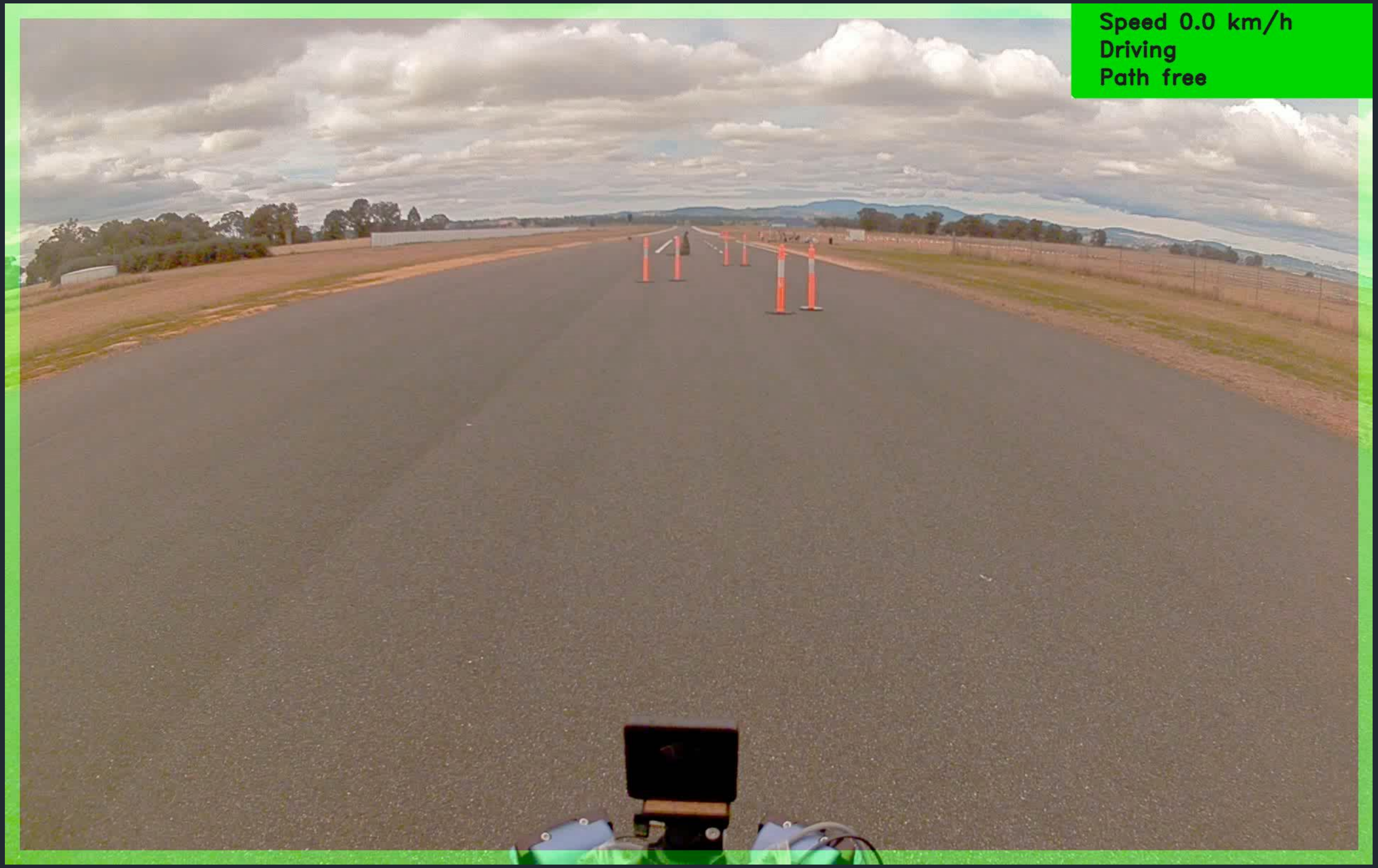
TEST BEDS AUTONOMOUS OPERATIONS

Locations: Crashlab (Huntingwood)



TEST BEDS AUTONOMOUS OPERATIONS

Locations: Cudal Future Mobility Testing and Research Centre



TEST BEDS AUTONOMOUS OPERATIONS

Locations: University of Sydney campus

TEST BEDS AUTONOMOUS OPERATIONS

Locations: Chippendale shared space/streets

TECHNOLOGY LEARNINGS – RESEARCH OUTCOMES

How the technology was developed/integrated to suit the environment
Focus on robustness (multi sensor fusion)

Better understanding of the technology challenges in various contexts

The expectations of pedestrians is different for roads and shared spaces.
Context specific behaviour

Working through the process of regulation with TfNSW
Opportunities for knowledge transfer

SHORTCOMINGS OF VERSION1 (ROS1)

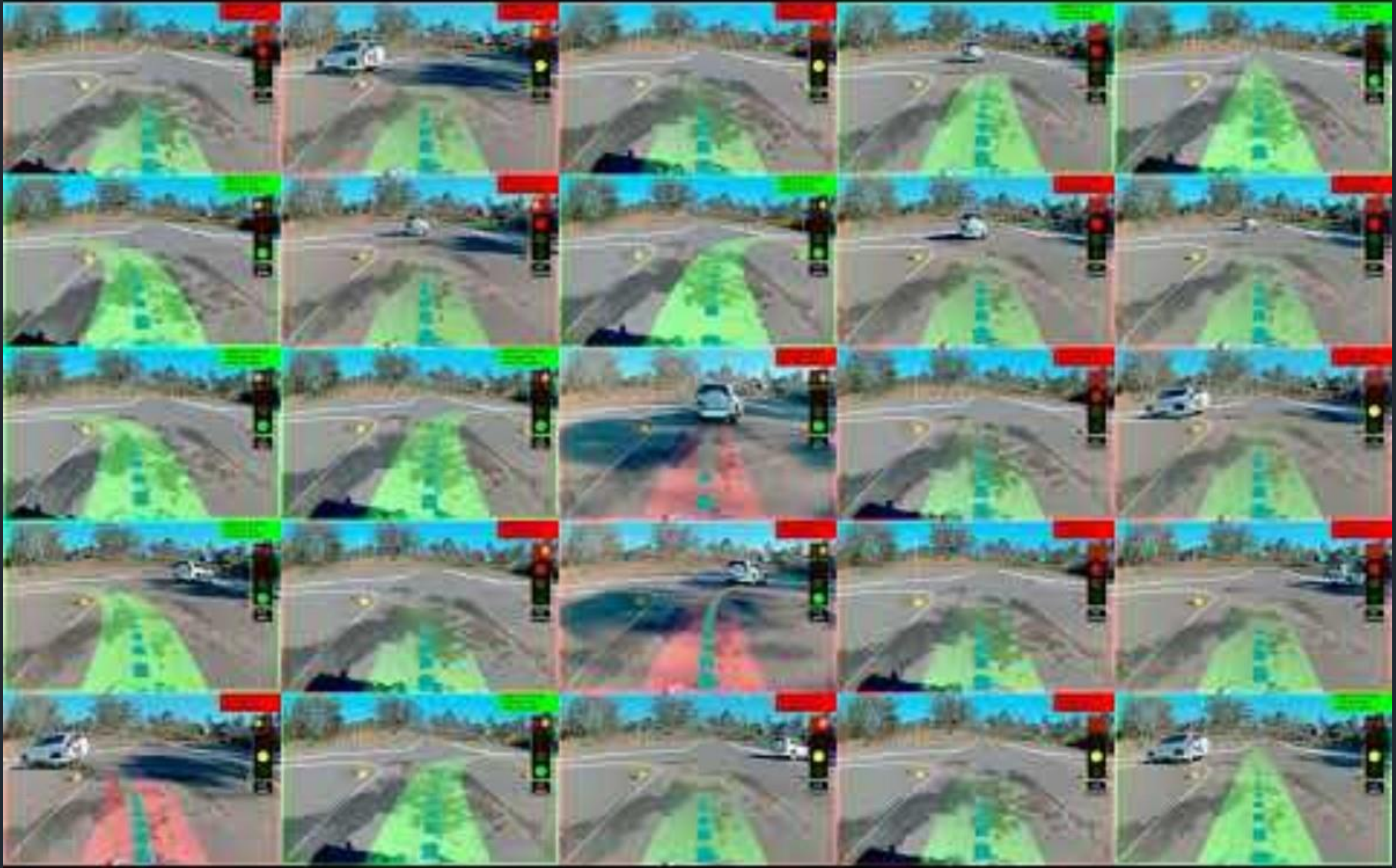
- ROS1 going end-of-life
- Support for new hardware/drivers
- Take advantage of significant updates to important stacks (nav/localisation)

COOPERATIVE ITS

V2X – DSRC

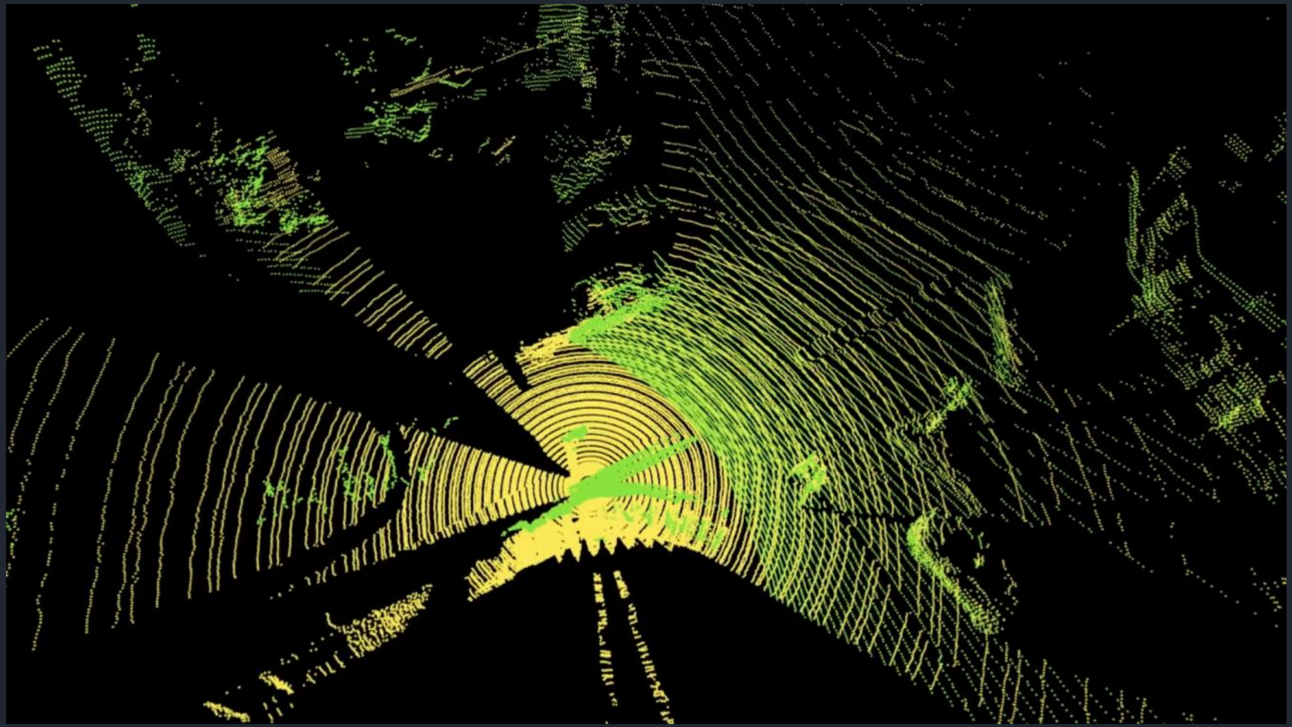
- Dedicated Short-Range Communications – peer-to-peer broadcast networking
- Cohda Mk5 OBUs are used for transmitting and receiving DSRC messages
- The DSRC messages are encoded/decoded pursuant to the ASN.1 standard
- Firmware for Mk5 developed to allow arbitrary payloads to be transported via ZeroMQ
  - Mk5 is just an endpoint

LAB TEST SETUP



DSRC – REAL WORLD DEPLOYMENT

- Intersection outside the Chippo broadcasts:
  - MAPEM – Map information about intersection routes
  - SPATEM – Signal Phase And Timing
- Vehicle only progresses through intersection when green
- EVs and VW Passat broadcast:
  - CAM – Cooperative Awareness Message
- This is used to yield to oncoming traffic



REAL-TIME SPATEM DATA

VERSION 2 – ROS2 PROJECT GEMINI

VERSION 2 – ROS2 PROJECT GEMINI

- Refurbishment of both vehicles
- Upgrade to ROS 2
- Return to feature parity between the vehicles
- Don't reinvent the wheel
  - Prefer hardware with OEM supported drivers
  - Use existing software stack where possible e.g. Nav2
  - **Push changes upstream (contribute)**
- Separate driver and experimenter interfaces
  - PDM for driver, screen for experimenter

VERSION 2 – ROS2 AUTONOMY STACK

- Everything is integrated into Nav2
- Three layers: route supervisor, planner, controller
- Route Supervisor receives "bus stop" and plots route along road
- Two stage planner:
  - Check if centreline path is collision free
  - If not, run Hybrid A* planner to goal pose
  - If both fail, shorten path and retry
- Controller is Pure Pursuit
  - Obstacle avoidance is performed by planner, not controller
  - Track the desired trajectory

ROS2 - PLC INTERFACE - CANOPEN

- Uses **ros-industrial ros2_canopen** package
- Needs a plugin to define CANOpen messages
  - e.g. subscribe to **Twist** message, convert to steering angles, and se nd to PLC
- Actual CANOpen protocol specifics dealt with by driver

WHY ROS 2?

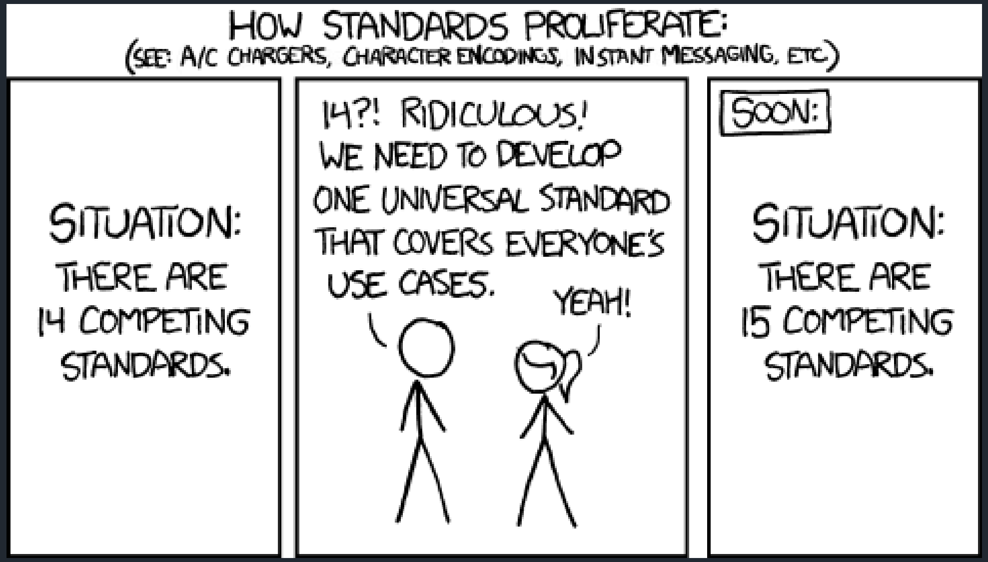
- We are a research institution and should be on the leading edge
  - No point contributing to ROS 1 upstream packages
- ROS 1 is EOL May 2025
- No *rosmaster*!
- Less and less devices have ROS 1 drivers
- Nav2 alone is worth the switch
- ROS 2 has a rolling release – latest changes available immediately

ROS 2 – PROS

- Composable nodes by default
- Python launch files
- Cleaner interfaces
- More modern C++ standards

ROS 2 – CONS

- Rapid release cycle means documentation is often not current
- Auto-discovery is multicast by default
  - Very slow and causes bandwidth problems
  - Default DDS ID means you see messages from anyone on ACFR network!



MAPS

- Use Lanelet2 (extension of OSM) for mapping road network
- Use SLAM toolbox to generate map for localisation
  - SLAM map datum is primary datum for all other components
- Transform UTM to map frame to align the two maps (partially automa ted process each time SLAM map changes or when mapping a new ar ea)
- Lanelets encode information such as speed limits and right-of-way at intersections

MAPS – LANELET2 MAP

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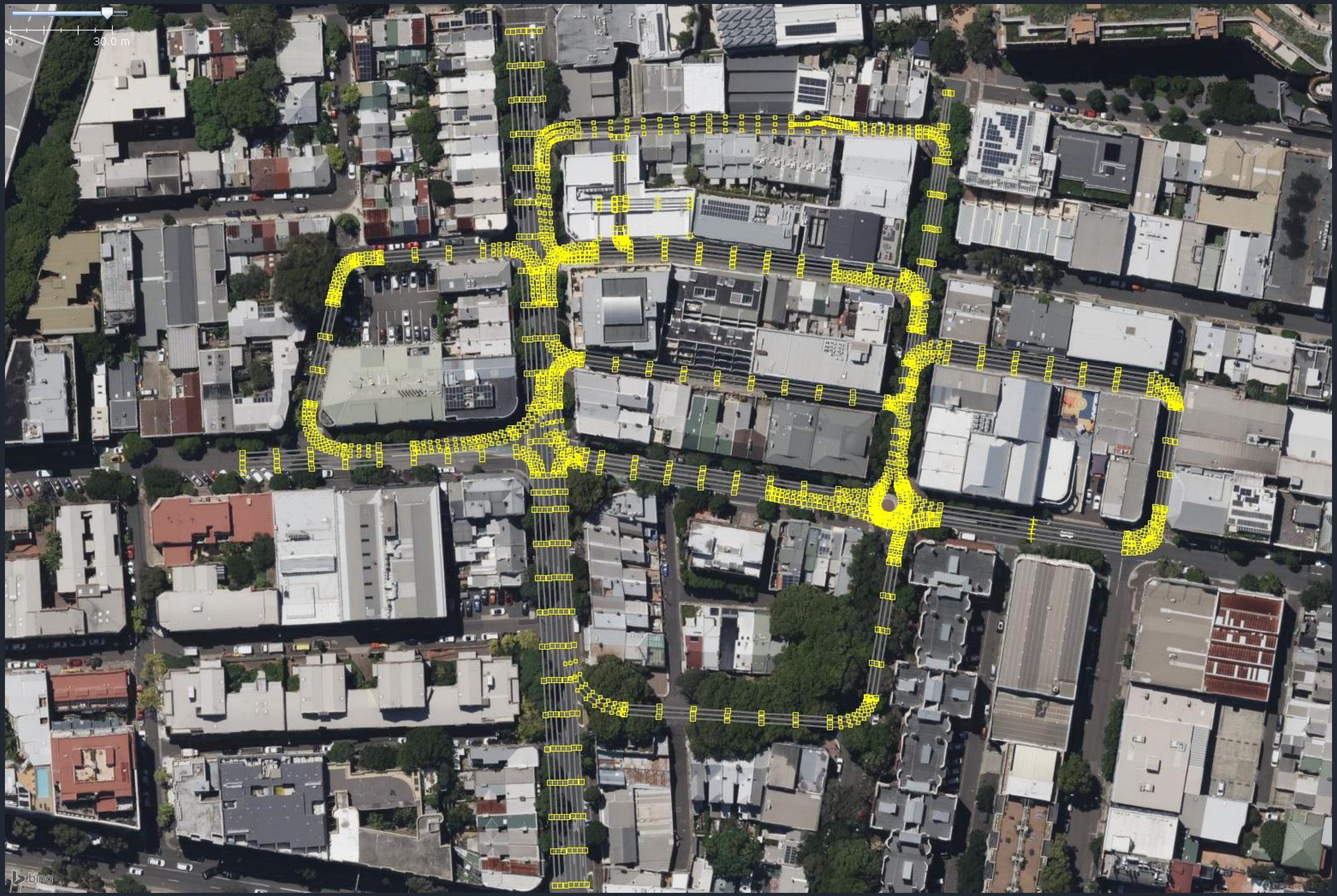
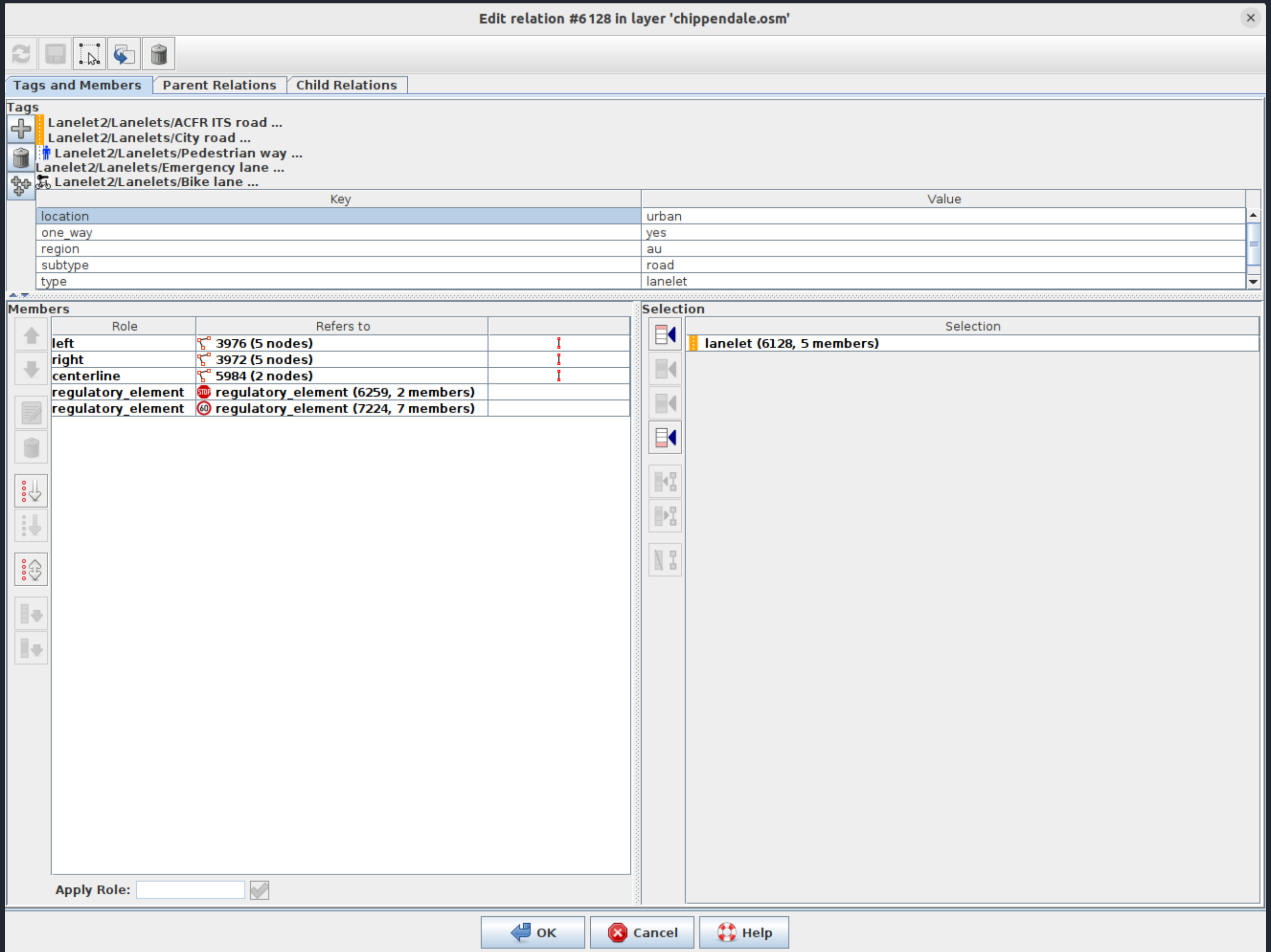


MAPS – LANELET2 MAP



LOCALISATION

Context specific

Lidar Features

Satellite (GNSS)

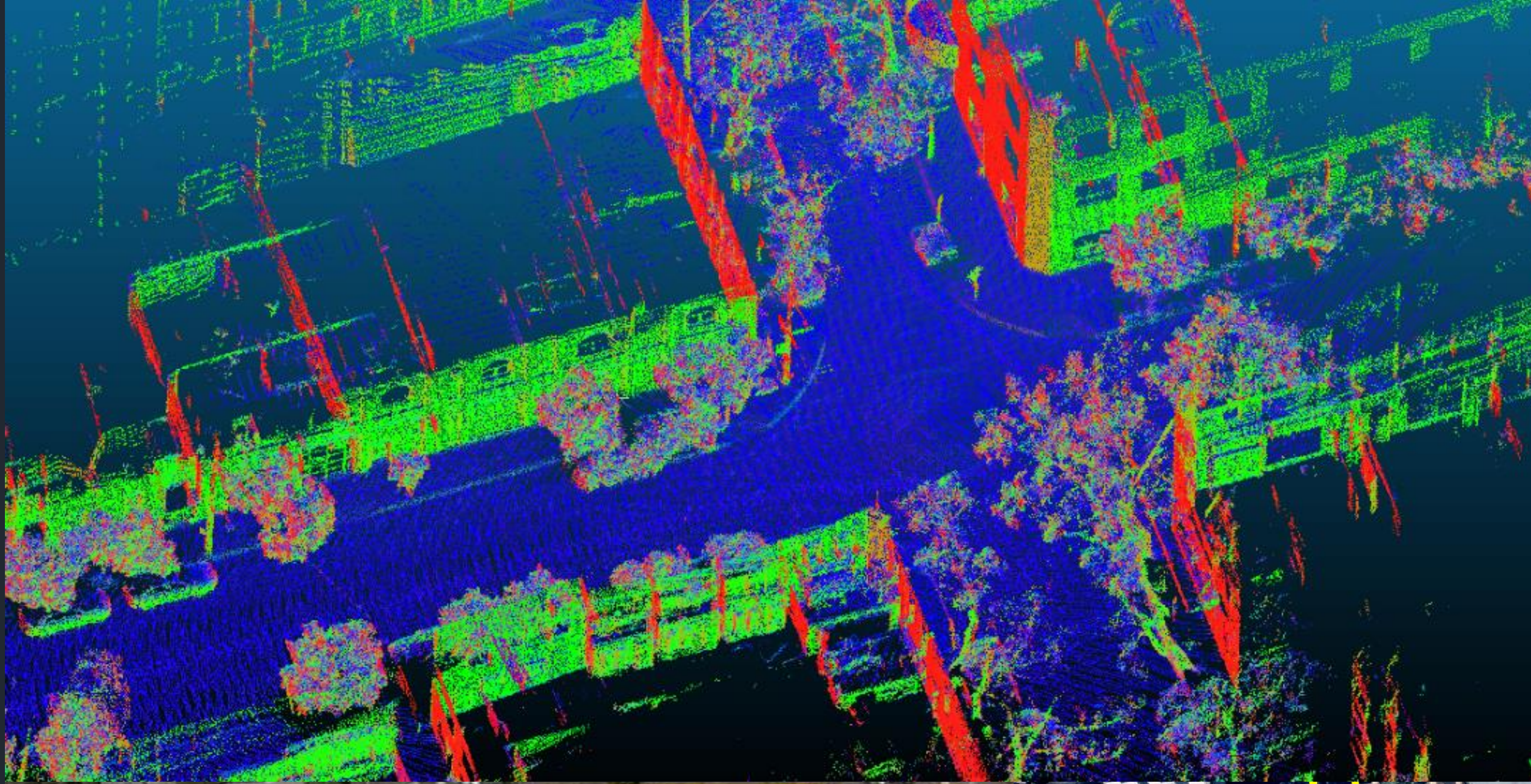
Dense lidar

Sensor Fusion

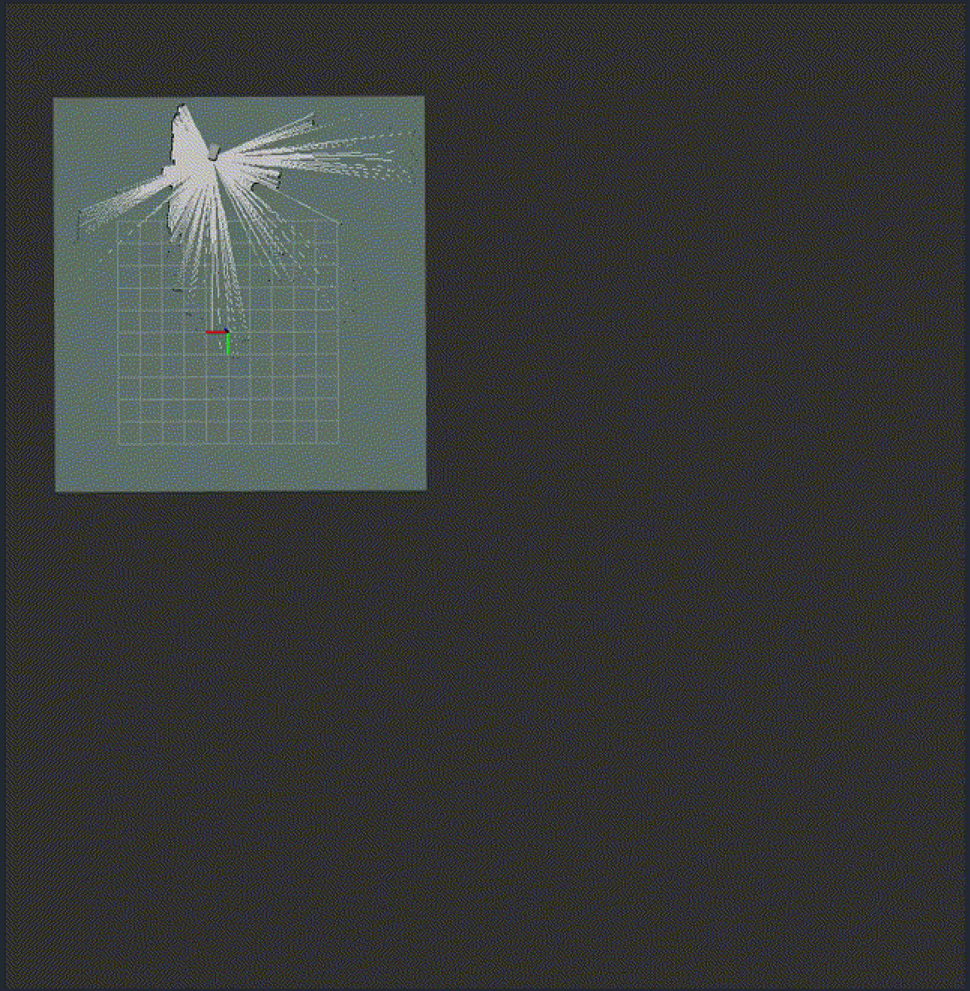
Inertial

ROS2

Fuse + **slam-toolbox**



MAPS – SLAM TOOLBOX



MOTION CONTROL

- Speed control performed by motor controllers
  - They can fight one another
  - Big shock loads on start
  - Legacy decision due to difficulty interfacing through PLC to close the loop in autonomous stack
- ROS 2 / Gemini makes interfacing easier
  - Will be switching to torque mode on motors, and closing the loop on PC
- Steering control through power steering motor
  - Underpowered but replacement requires major mechanical work

ROUTE SUPERVISOR

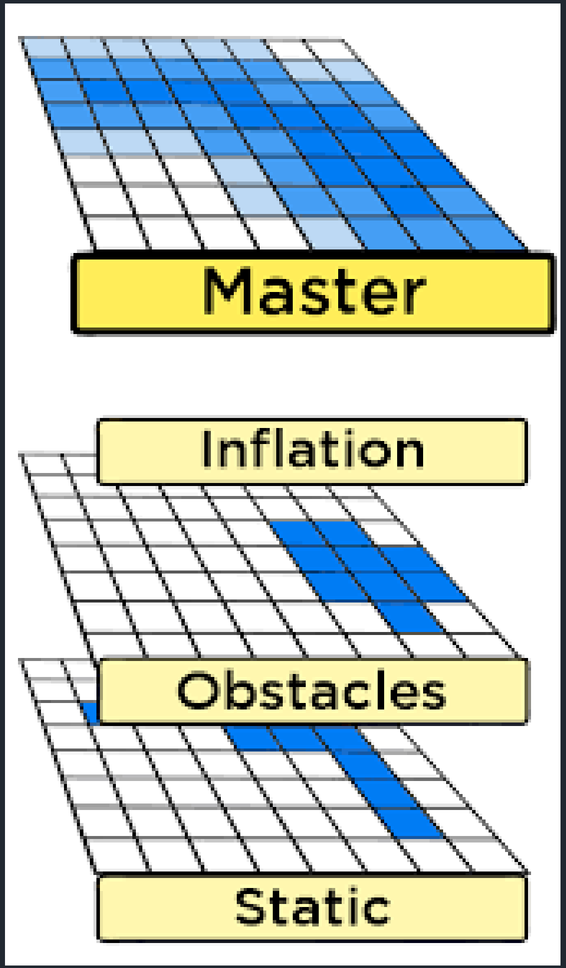
- Written in-house
  - Traditional planners either succeed or fail
  - We want to proceed as far as we can, e.g. following a car at traffic lights
- Generates centreline path from Lanelet2 map
- Plugins for Lanelet checkers (HumanInTheLoop, CAM, SPATEM)
- Prunes centreline path and sends poses to Nav2 stack

NAVIGATION

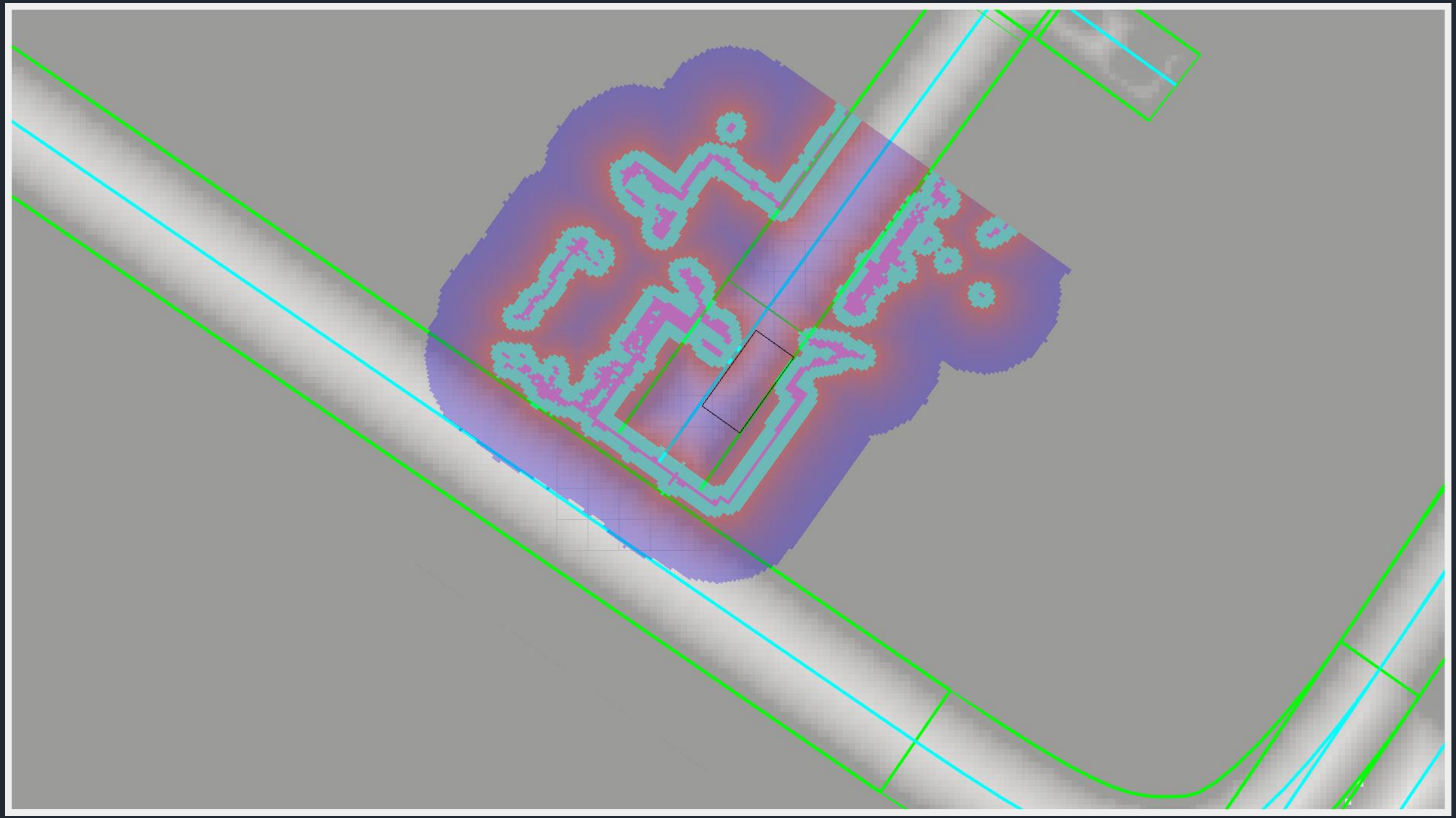
- Nav2 is highly capable for omnidirectional and Ackermann steered platforms
- Maintainer works full time on Nav2
  - Very responsive to feature development suggestions
  - High quality code
- Used by industry in deployed products

COSTMAPS

- Nav2 uses costmaps for planning
- Each costmap consists of *layers* that are combined in some way
- Each layer represents a type of information about the scene:
  - Static layer from Lanelet2 map
  - Obstacle layer from processed point clouds
  - Your layer here??

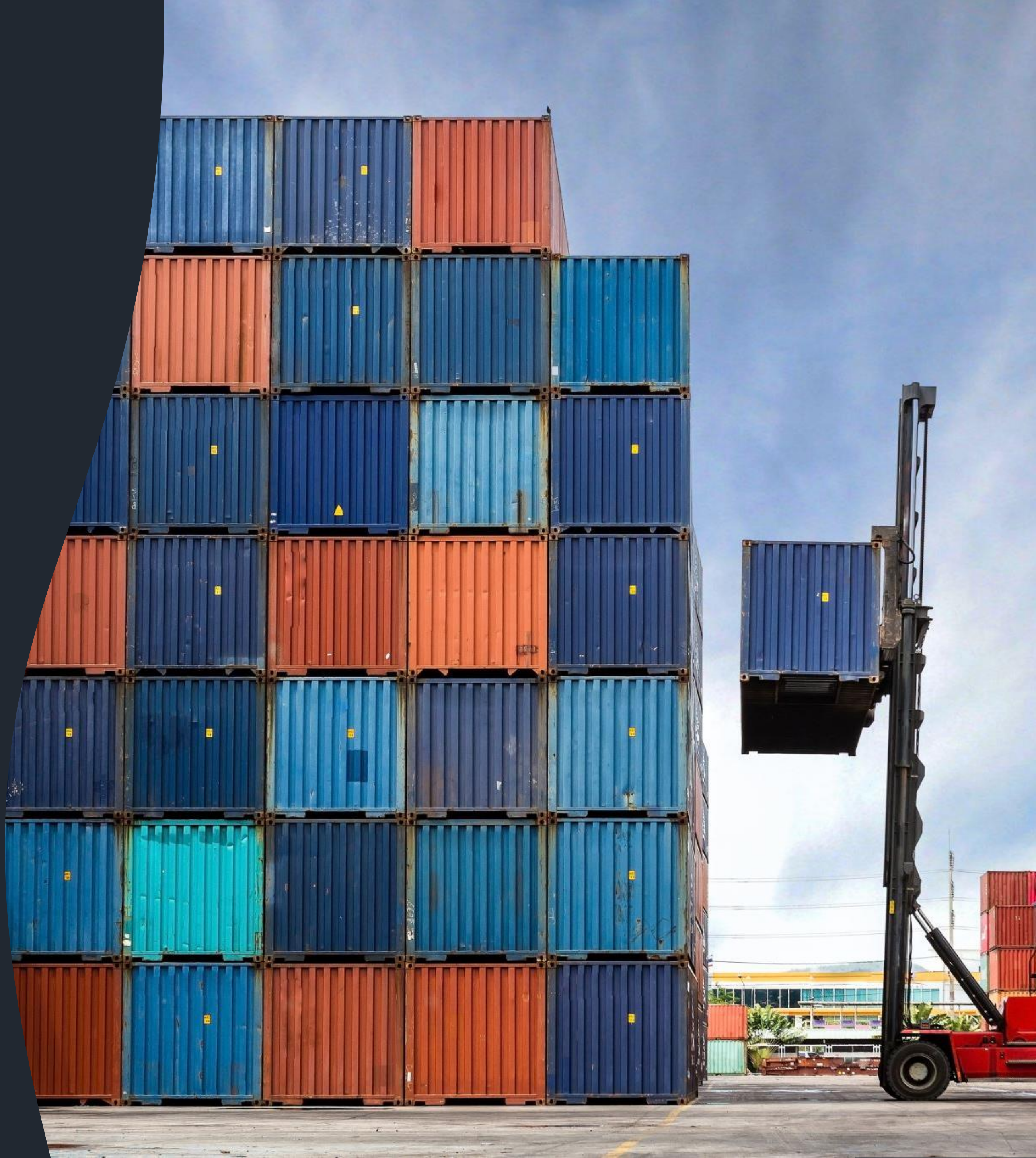


COSTMAPS



STACK MANAGEMENT AND DEPLOYMENT

- Packages are built by Gitlab
  - Built on push to mainline (*rolling* branch)
  - Nightly build to keep upstream updated
- Results in Docker image for each stack
- Pulled and run on vehicle using **docker compose**



VIDEO 2 - GEMINI GREATEST HITS

- Transition to ROS 2
- Install new self-contained battery
- New 128-beam lidar
- Significant rewiring
- PDM shows all driving related information
- DSRC – always sending CAM, and receiving CAM, MAPEM, SPATEM
- Design and install fast acting e-brake
- Install new compute
- Remove PX2 – all compute in one place

DATASETS – WHY ARE THEY SO HARD TO MAKE?

Few research groups have the equipment to make a comprehensive dataset

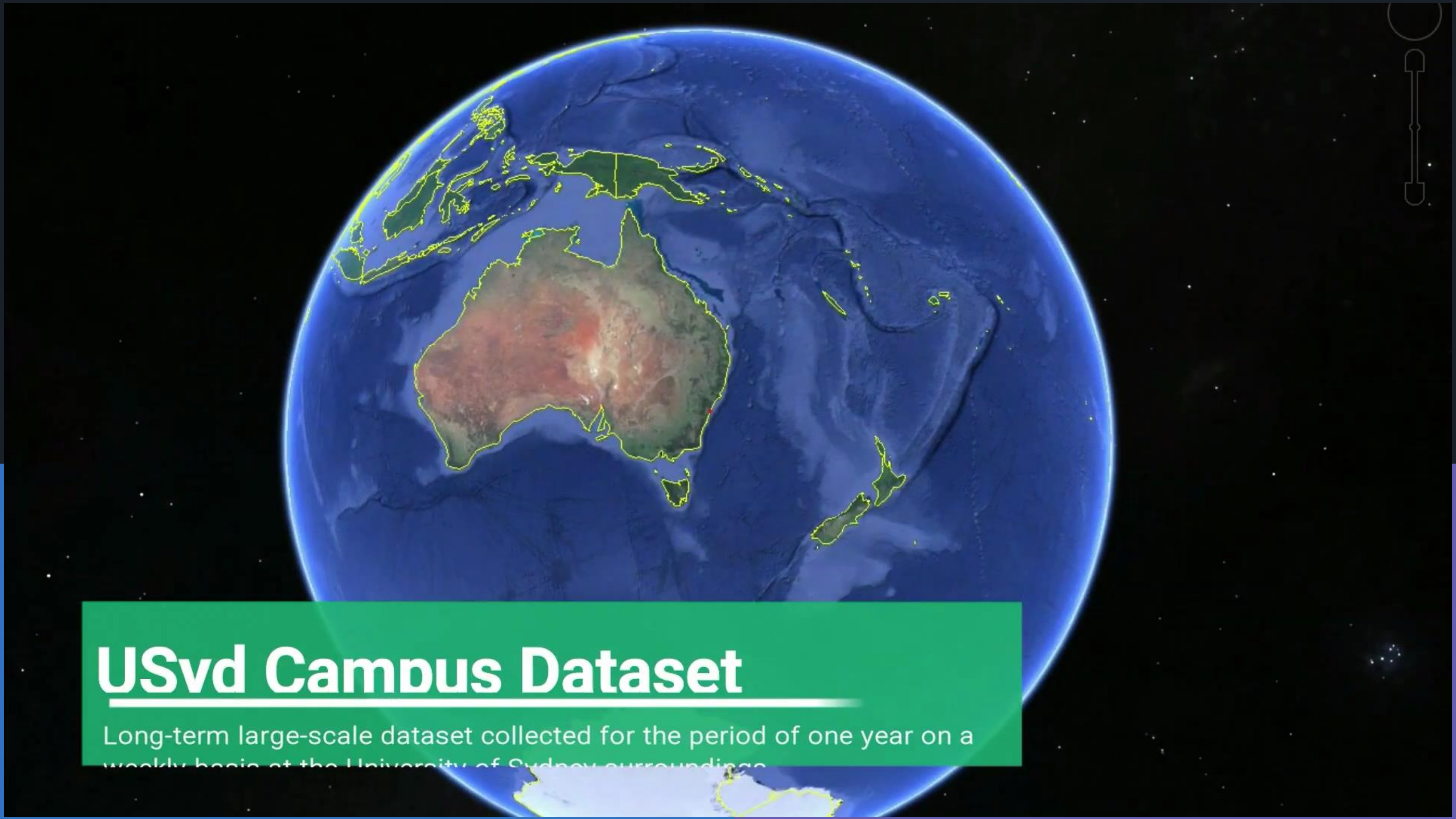
- Very resource intensive, and expensive

DATASETS – WHY ARE THEY SO HARD TO MAKE?

Our focus is on

- Uncertainty
- Multiple sensor modalities
- Calibration
- Synchronisation

DATA COLLECTION - USYD CAMPUS DATASET



W. Zhou*, S. Berrio*, S. Worrall, C. De Alvi, S. Mao, J. Ward and E. Nebot, "The usyd campus dataset" In IEEE Intelligent Transportation Systems Magazine (ITSM) 2020

Introducing: Vehicle-to-Everything Dataset