Cristina Olaveri-Monreal, Editor

The ACFR Centre: ITS Group

EDITOR'S NOTE

Please send your proposal on profiling research activities of your or other ITS research groups & labs in the ITS Research Lab Column to Cristina Olaverri-Monreal via olaverri@technikum-wien.at

Introduction

The Intelligent Transport Systems group is part of the Australian Centre for Field Robotics (ACFR). The ACFR centre objective is to undertake fundamental and applied research in field robotics and intelligent systems that encompass the development of new theories and methods, and the deployment of these into industrial, social and environmental applications. The ITS group has over 20 people including researchers, PhD students, technical support and visitors.

The ITS group has extensive support from industry at the national and international level. Current international project sponsors includes University of Michigan, Ford USA, Ibeo Germany and Renault France. The group is also part of the new Collaborative Research Centre iMove, and is currently working in two large projects with Transport for New South Wales and Cohda Wireless.

The main aim of the group is the development, deployment and demonstration of new mobility technology. The group has developed several Connected Autonomous Vehicles and is working with a number of industrial partners, government institutions and the University of Sydney to deploy and demonstrate innovative "smart city" concepts in various domains.

The research goals span various autonomous vehicle technologies with a strong focus on robustness, and providing safety guarantees for long term autonomous operations working under a wide range of urban scenarios. The focus on robustness and system verification covers all research topics.

The fundamental and applied research areas include:

- Autonomous Vehicle Platforms
- Perception
- Vision Based Semantic Deep Learning
- Localization
- Path Planning and Provably Safe Trajectories
- Driver - Pedestrian Intention Estimation
- Cooperative Perception

Vehicle Platforms

The group has built a number of platforms designed for research in vehicle automation and perception. Two autonomous electric vehicles were developed in a joint project with Applied EV, with the ACFR developing a computer controlled interface. Each vehicle contains two computers; an Intel NUC for drive control and an nVidia drive PX2 computing platform to handle the camera array. A PLC

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is used to provide a reliable low level interface with the vehicle hardware.

The vehicles have been fitted with a variety of sensors including a scanning 3D lidar, 360 degree vision through the inclusion of an array of six 1080p (30 Hz) cameras, inertial, GNSS, wheel encoders and various other sensors. These vehicles run ROS and are being used to compile a comprehensive weekly dataset driving around the campus at the University of Sydney over the period of more than one year. This dataset is being made available to the ITS community.

A Volkswagen Passat has also been fitted as a data collection vehicle with a sensor suite to collect trajectory data, and is able to identify and classify dynamic and static objects in proximity to the vehicle. The vehicle is fitted with a variety of sensors, including the lidar based Ibeo.HAD feature fusion detection and tracking system comprising of 6 Ibeo LUX lidar scanners to identify road users up to a range to 200 meters. This vehicle is used to collect naturalistic driving data including tracked objects, which is used in many of our projects.

Electrical vehicles retrofitted with automation technology and logging capabilities.

Urban vehicle retrofitted with 360 degrees perception, high accuracy localization and logging capabilities.

Semantic information from multiple cameras.

Perception

The group has a strong focus on perception, using multiple cameras and

PAPERS

RELATED PAPERS PERCEPTION:

- Wei Zhou, Stephany Berrio, Worrall Stewart, Nebot Eduardo, "Automated Evaluation of Semantic Segmentation Robustness for Autonomous Driving", in *IEEE Transactions on Intelligent Transportation Systems*. doi:10.1109/TITS.2019.2909066, http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=8691698&isnumber=4358928
- Wei Zhou, Worrall Stewart, Nebot Eduardo, "Adapting Semantic Segmentation Models for Changes in Illumination and Camera Perspective", IEEE Robotics and Automation Letters 4(2): 461–468 (2019)
- Charika De Alvis, Mao Shan, Worrall Stewart, Nebot Eduardo, "Uncertainty Estimation for Projecting Lidar Points onto Camera Images for Moving Platforms", In the IEEE Conference on Robotics and Automations, Montreal, 2019.
- Zhou W., Arroyo R., A. Zyner, J. Ward, S. Worrall, E. Nebot , Bergasa L."Transferring Visual Knowledge for a Robust Road Environment Perception in Intelligent Vehicles", 2017 IEEE 20th International Conference on Intelligent Transportation Systems (ITSC), Yokohama, 2017, pp. 1–6.

lidar to robustly perceive important features in the urban environment. The detection of objects is used in collision avoidance, object tracking, mapping and localization. The group is also publishing a comprehensive dataset with weekly driving data taken over the course of an entire year. Our work has included automatic calibration of the intrinsic and extrinsic parameters to estimate the geometric relationships between the sensors.

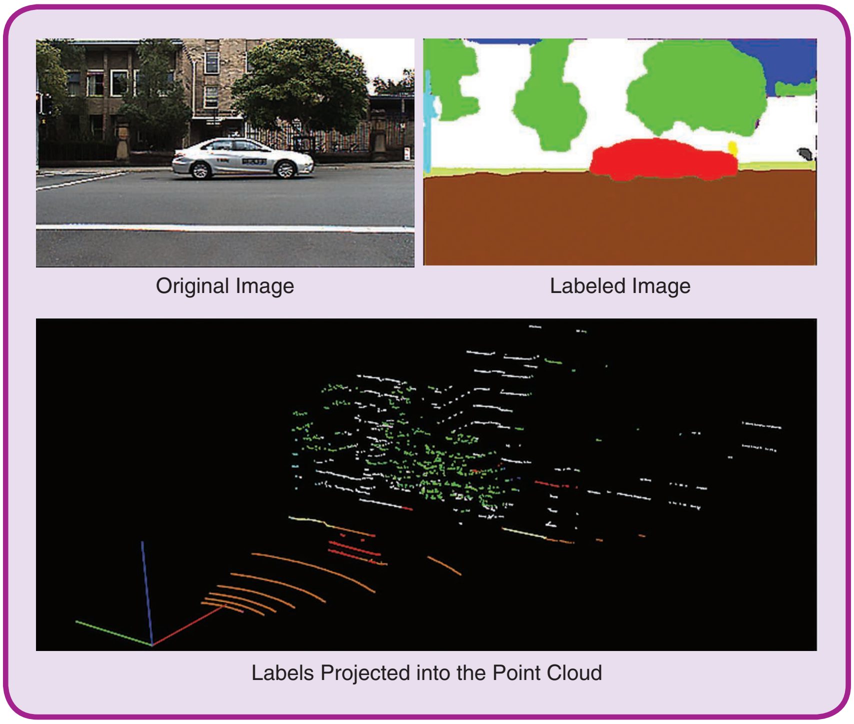
Multiple camera view and laser projection. The picture shows the accuracy of the extrinsic calibration process.

Vision Based Semantic Deep Learning

One of the fundamental challenges in the design of perception systems for autonomous vehicles is validating the performance of each algorithm under a comprehensive variety of operating conditions. In the case of vision-based semantic segmentation, there are known issues when encountering new scenarios that are sufficiently different to the training data. In addition, even small variations in environmental conditions such as illumination and precipitation can affect the classification performance of the segmentation model.

Given the reliance on visual information, these effects often translate into poor semantic pixel classification which can potentially lead to catastrophic consequences when driving autonomously. This research area examines novel methods for analyzing the robustness and reliability of semantic segmentation models when operating in diverse environments. The aim is to provide metrics for the evaluation of the classification performance over a variety of environmental conditions. Another aspect of this research is the automated generation of labels using different sensing modalities. This combined with the yearly dataset can generate more robust models that are capable of handling a wider variety of conditions without expensive hand labeling.

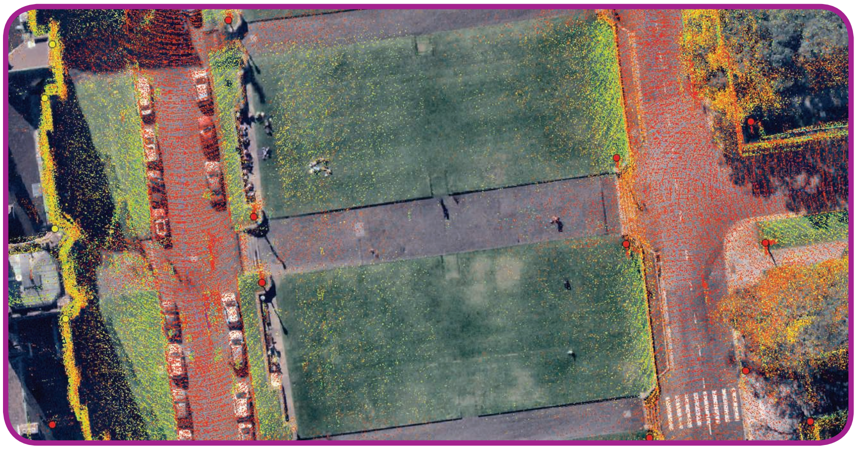
The same location viewed at various times of the year from our yearly dataset. There are considerable changes to the lighting conditions.



Calibration, projecting semantic information into a point cloud.

Localization

Robustness and safety are crucial properties for the real-world application of



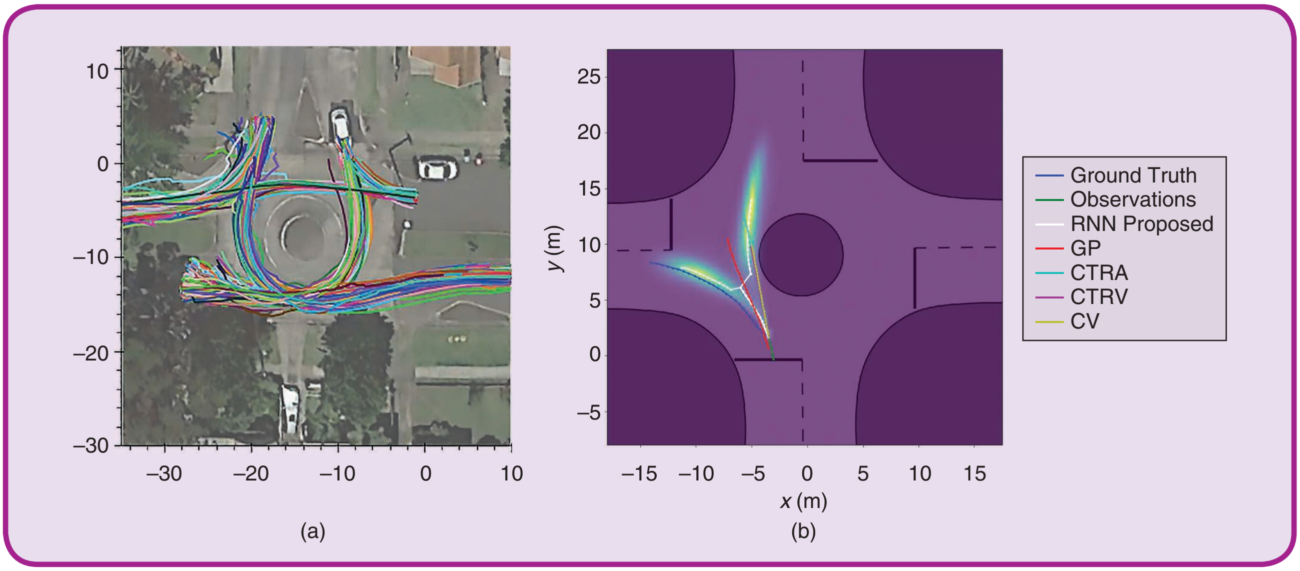
Point cloud registered to a global map and aerial imagery.

A lane based map showing the high level features of the road network.

autonomous vehicles. One of the most critical components of any autonomous system is localization. During the last 20 years there has been significant progress in this area with the introduction of very efficient algorithms for mapping, localization and SLAM. Many of these algorithms present impressive demonstrations for a particular domain, but fail to operate reliably with changes to the operating environment. The aspect of robustness has not received enough attention and localization systems for self-driving vehicle applications are seldom evaluated for their robustness.

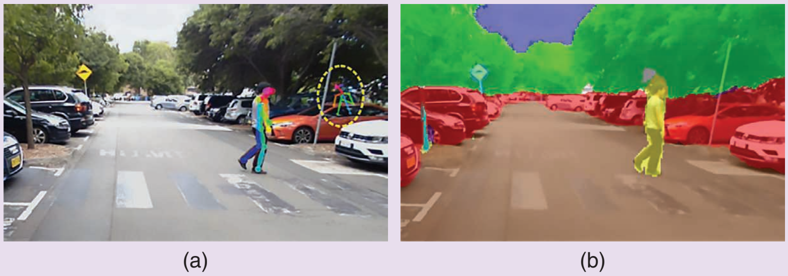
Our work in this area focuses on using multimodal sensor fusion to build feature and semantic maps of the environment. The features observed in the relative coordinate systems are registered to a global reference frame using graph optimization techniques. The projects aims at developing and demonstrating large area localization algorithms and the introduction of novel metrics to effectively quantify localization robustness with or without an accurate ground truth.

The feature maps generated during localization provide prior information for future localization and path planning. The challenge in maintaining this map comes as a result of changes



Naturalistic data Datasets and RNN model to predict driver maneuvers.

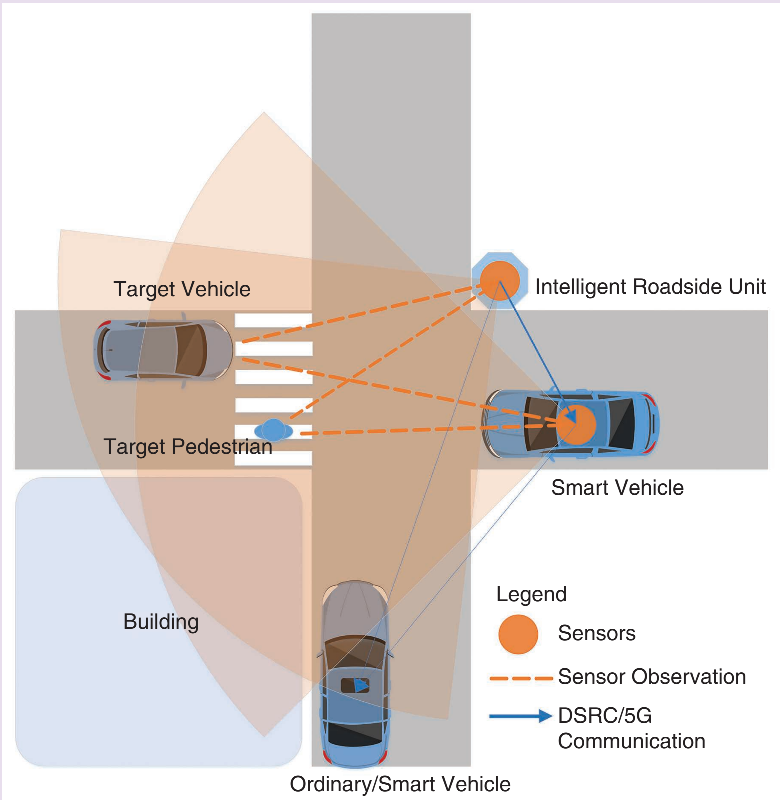
over time within the urban environment. In our yearly dataset, there are numerous examples of buildings that are built/removed and other features like trees/poles that change over time. One important outcome of the work from our group is the development of new techniques to maintain a global map over a long time frame, utilizing a probabilistic approach which can be incorporated into the localization task.



Fusion of semantic and skeleton tracking to improve robustness.

Path Planning and Provably Safe Trajectories

Planning safe trajectories for autonomous vehicles is challenging, particularly when operating around dynamic obstacles. Our electric vehicles planning strategy is divided into a high level path planner and a low level robust collision avoidance algorithm referred to as a "virtual bumper". The high level planner is interchangeable depending on the location and complexity of the situation. Using high level features of the road network including information about the lanes/curbstones and road rules the high level planner can generate detailed trajectories in line with the expected behavior of a vehicle. The low level collision avoidance is designed primarily as a last resort in the event of an unexpected obstacle. These components are being developed to include tracking and prediction of obstacles to reduce the amount of false alarms and to operate in highly dynamic environments such as shared pedestrian areas. In addition, we are collaborating with the University of Michigan to incorporate a reachability based trajectory planner that is provably safe.



Example showing the benefit of cooperative perception integrating vehicles and IRSU sensing.

Driver - Pedestrian Intention Estimation

Driving vehicles is a highly skilled task that requires extensive understanding of the intentions of other road users. A limitation of current Advanced Driver Assistance Systems (ADAS) systems is the inability to perceive the entirety of the vehicle situational context and the intentions of the human participants. Available sensor systems cannot understand a vehicle's surroundings anywhere near as accurately and comprehensively as a human driver. Humans interpret situations and anticipate likely events by combining past experiences, sensory input and a multitude of behavioral cues. While this may become second nature to an experienced human driver, properly understanding the intentions of other drivers and pedestrians is still an unsolved problem for ADAS, and by extension, autonomous vehicles.

Our projects in this area address driver/pedestrian intention, and path prediction using machine learning approaches including RNNs and deep learning to improve the robustness of the estimation process. These data driven approaches have incorporated naturalistic vehicle trajectories

LOCALIZATION

- Siqi Yi, Worrall Stewart, Nebot Eduardo, "Metrics for the Evaluation of Localisation Robustness", accepted for publication in 2019 IEEE Intelligent Vehicles Symposium (IV) (IV2019), June 9–12, 2019, in Paris, France
- Berrio Stephany, Ward James, Worrall Stewart, Nebot Eduardo, "Identifying robust landmarks in feature-based maps", accepted for publication in 2019 IEEE Intelligent Vehicles Symposium (IV) (IV2019), June 9–12, 2019, in Paris, France

DRIVER PEDESTRIAN INTENTION

- Zyner Alex, Worrall Stewart, Nebot Eduardo, "Naturalistic Driver Intention and Path Prediction using Recurrent Neural Networks, Accepted IEEE Intelligent Transport System Transaction, April 2019
- Asher Bender. Gabriel Agamennoni, James R. Ward, Stewart Worrall, and Eduardo M. Nebot – "An Unsupervised Approach for Inferring Driver Behavior From Naturalistic Driving Data", IEEE Transaction of Intelligent Transportation Systems, Year: 2015, Volume: 16, Issue 6, pp. 3325 –3336.
- Zyner Alex, Worrall Stewart, Nebot Eduardo, "ACFR Five Roundabouts Dataset: Naturalistic Driving at Unsignalised Intersections, Accepted IEEE Intelligent Transport System Magazine, Feb 2019.
- Zyner Alex, Worrall Stewart, Nebot Eduardo, "A Recurrent Neural Network Solution for Predicting Driver Intention at Unsignalised Intersections" IEEE Robotics and Automation letters, vol. 3, No 3, July 2018, pp 1759–1764.
- Konrad S, Shan M, Masson F, Worrall S, Nebot E." Pedestrian Dynamic and Kinematic Information Obtained from Vision Sensors.", 2018 IEEE Intelligent Vehicle Symposium, pp 1299–1305

collected by our platforms. These large naturalistic datasets provide valuable information that is typical of the data available from an autonomous/smart vehicle. We are publishing the datasets for the ITS community.

Cooperative Perception

The next decade will see the massive deployment of Vehicle to Vehicle and Vehicle to Infrastructure communication. The availability of large scale egocentric and external sensor information will enable the development of highly sophisticated cooperative safety solutions. The upcoming widespread deployment of DSRC technology will enable the sharing of a multitude of information that can potentially be used to build accurate representations of the local environment. This information will be provided by intelligent Road Side Units (IRSU) infrastructure and smart vehicles fitted with communication hardware and advanced perception capabilities.

The projects in this area focus on the development of a general framework for cooperative data fusion to integrate data coming from different sources with their own uncertainties. These algorithms will be used to propagate estimates of position, context and associated risk for all road users and vehicles in proximity. This information will be critical to extend the sensing capabilities of smart vehicles beyond the visual line of sight, which in complex traffic scenarios can be heavily restricted.

Future Direction

The group will look to integrate each of the components of urban vehicle automation to guarantee a high level of reliability, and provide an assurance of safety. The future direction will also consider the human machine interface required to enable seamless interaction between autonomous vehicles and people. The next generation of projects will look at the development and integration of these technologies to enable the adoption of new forms of innovative mobility that will be an essential part of future cities.

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ERRATA

Due to a production error in "Understanding Individualization Driving States via Latent Dirichlet Allocation Model" in the Summer 2019 issue of *Intelligent Transportation Systems* [1], the names of the corresponding authors, Yishi Zhang and Chaozhong Wu, were omitted. The statement "Zhijun Chen and Yishi Zhang contributed equally to this work" should have been published in the article. In addition, the acknowledgment section was inadvertently removed.

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We sincerely apologize for these oversights and any confusion they may have caused.

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Reference

[1] Z. Chen, Y. Zhang, C. Wu, and B. Ran, "Understanding individualization driving states via Latent Dirichlet Allocation model," *Intell. Transp. Syst.*, vol. 11, no. 2, pp. 41–53, 2019.

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