EURORACING

Introduction - Team composition

Autonomous racing gives the opportunity to convey research and industry efforts in one spectacular, open sky, laboratory. The Indy Autonomous Challenge is the perfect environment for taking years of fundamental and road-relevant research together, while boosting the creation of new technology and promoting autonomous driving to the general public.

To tackle the technical challenges envisioned by Indy Autonomous consortium, EURORACING is composed of groups with expertise in all the areas required for a successful race.

In particular, the partners have experience in designing, maintaining, developing both software and hardware to operate autonomous racing vehicles at all scales.

UNIMORE: University of Modena and Reggio Emilia

The High-Performance Real-Time Laboratory (HiPeRT Lab - https://hipert.unimore.it) was founded in 2012 at the University of Modena and Reggio Emilia. It involves more than 40 researchers developing algorithmic and software solutions for high-performance real-time system, with key strategical partnerships with NVIDIA, Xilinx, and top automotive Tier 1 and OEMs such as Bosch, Maserati, Ferrari, Magneti Marelli and Danisi Engineering. The lab hosts multiple working prototypes of autonomous vehicles such as L3/4 cars, delivery bots, RC models, drones, etc. HiPeRT designed, and maintains, the Modena Automotive Smart Area, a 2sqkm urban area hosting testing and validation of AD systems/ADAS, and highly-connected vehicles.

HiPeRT is also in the core organization team of the F1/10th autonomous racing competition (http://f1tenth.org), for which they built four working prototypes.

The HiPeRT Lab is also scientific advisor of the Driverless Formula SAE UNIMORE team, which will be involved as well in the project, and work on the maintenance and setup of the Indy Autonomous vehicle. For this reason, HiPeRT/UNIMORE facilities will be the main integration hub for the vehicle. This will also facilitate engagement with automakers in the spirit of Indy Autonomous goals, which are heavily present in the Modena area, right at the core of Italian Motor Valley.

UNIPI: University of Pisa - Research Centre E. Piaggio

The Research Centre E. Piaggio at the University of Pisa (UNIPI) (http://www.centropiaggio.unipi.it/) is one of the oldest interdisciplinary technology transfer centers in Europe. It employs experienced researchers in the design, realization and control of complex machines such as humanoid robots (the development of WALK-MAN robot for participation in 2015 DARPA Robotics Challenge, https://www.walk-man.eu/), mobile robots, industrial manipulators and components such as robotic hands. Here the first Italian Roborace

Team (www.roboteamitalia.it) was created, to compete in the Roborace championship, which is similar in nature and scale to Indy Autonomous. The experience gathered in this kind of full scale racing involves the development of a full stack of perception and control software to race the car in a track, as well as software integration and deployment on multiple vehicles.
After taking part in 2019 Roborace Season Alpha, whose main focus was on localization in a GPS-denied scenario using only LiDAR sensors, 2020 will see the team facing the problem of autonomous overtaking and avoidance of dynamic obstacles. These goals nicely match with the ambitious ones set by Indy Autonomous. Technical lead of the autonomous driving infrastructure will be the main responsibility of this team.
UNIPI plans to involve 15 people.

ETH Zurich

The ETH Zurich Autonomous Indy team is a combination of students and researchers at the university with a variety of backgrounds in robotics and control. The team members worked on several autonomous racing projects over the last 8 years. One example is the ORCA project hosted at the electrical engineering department, where a full planning stack was developed which allows to race miniature autonomous race cars wheel-to-wheel. This project also produced some of the core academic publications in the area of optimization-based motion planning for autonomous racing. The second example is the AMZ formula student driverless team, even though the Autonomous Indy team is not affiliated with AMZ, many members of the team are AMZ driverless alumni. AMZ driverless has won first place in the past 3 years of the Formula Student Driverless competitions. Within the AMZ driverless project, the team members developed a complete autonomous racing pipeline from sensors to actuators including all the autonomous software in between. The ETH Zurich team will consist of 7 people.

POLISH ACADEMY OF SCIENCES

PAN team is focused on practical application of research. It focuses on applying 3D SLAM using GPGPUs on mobile robots for interventions in harsh environments. This experience helped in the development of an on-line localization method based on 3D point clouds for both map and measurements. The team has also experience in competitions such as DARPA VRC, ELROB, Eurathlon, Udacity challenge, and in Self-Racing cars competitions such as Self-Racing Cars 2017, 2018 and won F1/10 competitions in Turin 2018 and New York 2019. PAN members are also actively involved in the organization of Warsaw Self-Driving Cars meetups, Self-Driving Car Nanodegree by Udacity, and F1/10 competition.

Software Architecture

Autonomous Racing (AR) requires the ability to swiftly elaborate sensor inputs, motion plans and control actions. The operating speed and proximity conditions sought after in Indy Autonomous pose unprecedented challenges that will require novel solutions to be developed in a short time frame. Modularity will be a tool to guarantee rapid integration of new solutions.

The functionalities required for AR and our plan for implementation and adaptation are shortly outlined in the following.

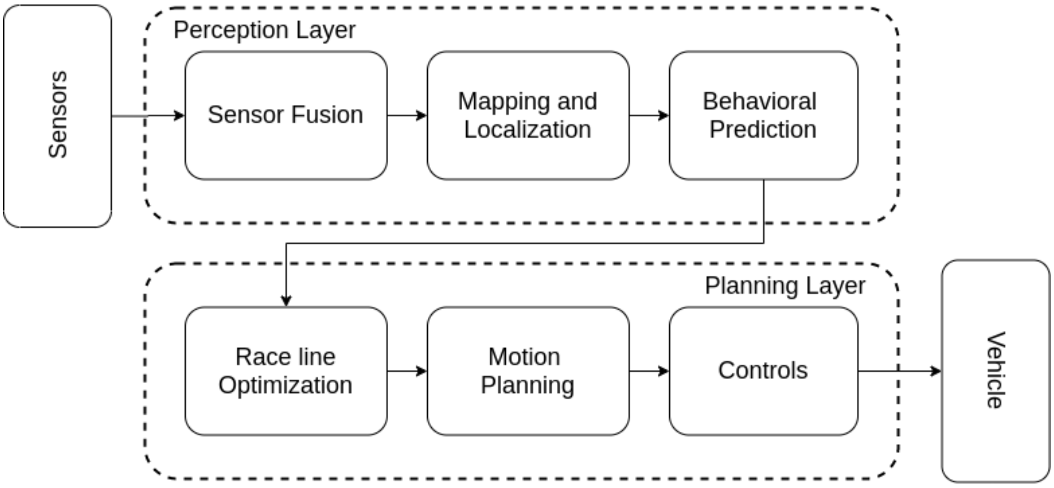

Figure YY - High level racing software architecture

PERCEPTION LAYER

SENSOR FUSION

Perception for an autonomous vehicle requires dealing with noisy and possibly faulty signals to provide consistent and accurate state estimates of ego and other vehicles' state. At the foundation of each of the subsequent blocks there will be a filtering layer. Both navigation (e.g., GNSS/GPS, inertial, cameras, radars) sensors and proprioceptive sensors (e.g., temperature of wheels, suspension rod elongation) will be integrated to provide input to other perception and planning modules with different levels of detail. In particular, wheel-road friction will be estimated online to provide input to the motion planning module.

MAPPING AND LOCALIZATION

Mapping: a geometrical representation of the track is needed to perform raceline optimization and online motion planning. Given the particular geometry of Indianapolis Motor Speedway, a simple 2D description of the track might not suffice as information on road camber angle can be exploited to improve lap time. On top of the geometrical map, other semantic (e.g. starting position, finish line, areas forbidden for overtaking) or physical (e.g. higher/lower grip available) track features might be embedded in the map.

Localisation: technical challenges are expected for localisation of the car at high speed.
This affects the development of each team, which will be required to correctly estimate their own vehicle's position, and collectively the whole competing teams, as a centralized supervisor might be available to monitor the racing and enforce safety measures (e.g. stop a vehicle) in case of malfunctioning.
Concrete solutions for ego-vehicle localisation will most likely rely on a combination of RTK-GPS, inertial, wheel odometry and LiDAR-based scan matching, while cameras might be more relevant for object detection due to the presence of motion blur at certain speed regimes.

Solutions for GPS-denied environments are also available and have been tested from UNIPI in the context of 2019 Roborace Season Alpha.

BEHAVIORAL PREDICTION

Prediction of other vehicles' behavior is recognized as one of the most challenging and road-relevant problems in the autonomous vehicles community. The capability of smoothly moving within an inherently uncertain and dynamic environment is considered as one of the main enablers of true Level 5 autonomy. The racing environment poses somewhat similar problems, as the opponents have a pretty well known dynamics but uncertain high level strategies. The extreme operating conditions foreseen by current Indy Autonomous Regulations are the perfect stimulus for finding original solutions to this problem, which is currently an active area of research.

PLANNING LAYER

RACE LINE OPTIMIZATION

In this phase, whenever possible, car setup will be optimized for the specific track. Given the presence of multiple competing vehicles on track more relevance will be given to online motion planning. Still, state of the art methods will be employed to compute an ideal racing line as a starting point for qualification and performance validation.

MOTION PLANNING

Motion planning for autonomous racing is a challenging task, since it requires planning motion at the limit of handling, where the behavior of the tires are highly nonlinear and the longitudinal and lateral motion is coupled. At the same time, to successfully overtake other cars, the motion planner also needs to consider all the possible motions of the other cars and plan trajectories that are wheel-to-wheel.

One approach that has been shown to work in this setting is the combination of graph-based planners that are able to consider tactical decision, and optimization-based techniques, that are suited to deal with the highly nonlinear dynamics while guaranteeing that the planned motion is collision-free. We will also investigate machine-learning based approaches that allow us to improve the vehicle model and consider different friction levels in different parts of the race track. Finally, we believe that the expertise of our team in high performance computing and motion planning can achieve the challenging task of making these approaches feasible in real-time.

CONTROL

For autonomous racing, a high level control interface is usually made available on the vehicle, such as gear, torque/acceleration or steering/curvature. Independent wheel braking will allow performance improvements during turning at the limits of friction. Low level control must ensure proper tracking of desired commands at all operating conditions. The team has experience in developing and implementing hardware and software solutions in these areas.

Nonetheless, a common software interface is expected to be specified by the Indy Autonomous regulations, to define how the teams should control the car at the lower level.

HARDWARE-SPECIFIC OPTIMIZATION, AND SIMULATION

The trend in the automotive industry is to move towards E/E vehicle designs, where "traditional" simple ECUs communicate with a (replicated) centralized decisional system deployed in a *domain controller* computing platform, which delivers tremendous TOPS performance capabilities at reduced Size, Weight and Power (SWaP). This is possible thanks to the adoption of heterogeneous embedded architectures, with multi-core power-efficient host and data crunching accelerators, such as GPGPUs and Deep Learning Accelerators (DLAs).

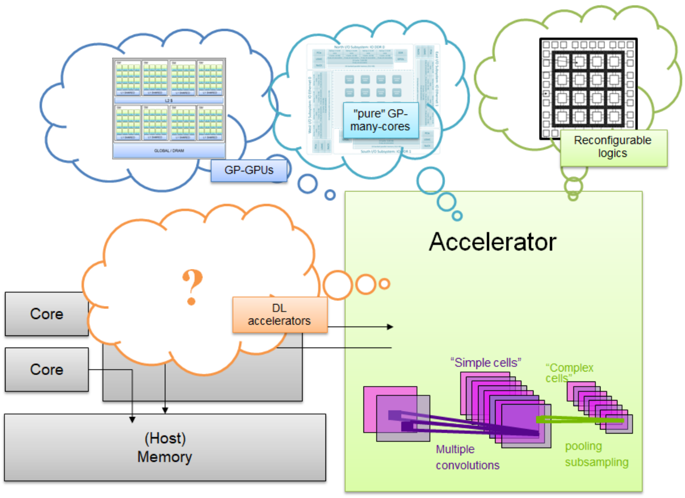

Figure XX - Architectural template for heterogeneous computing platform with embedded deep-learning accelerator

To extract the best end-to-end performance from the driving computing stack, specific optimizations of the software components are required for the targeted hardware. For example, NVIDIA Drive AGX, one of the most widely adopted platforms for AD prototyping, features a host multi-core cluster, an integrated GPGPU and multiple accelerators for vision workloads and neural inference. Properly programming these platforms so that all performance and real-time requirements are met is a complex task even for skilled programmers. The HiPeRT Lab at University of Modena and Reggio Emilia has a wide expertise in this field, with longstanding collaborations with high-performance embedded platforms providers, such as Nvidia, Xilinx and Huawei. HiPeRT will contribute to the project porting its AD system stack, named TK, designed to maximize real-time performance on next-gen embedded platforms.

Adapting existing solutions and extending them to real races requires a significant effort, exposing to multiple error-prone decisions. This is clearly unacceptable in a domain such as car races, where human intervention and monitoring is still necessary at the development stage, and where equipment is extremely expensive. For this reason, extensive prototyping is necessary, with simulator infrastructures with Hardware-in-the-Loop capabilities[1], and accurate modeling of vehicle dynamics, and of the physics of the surrounding environment. We intend to customize a vehicle simulator currently adopted by Dallara, featuring an accurate model of the vehicle and extending it to test our planning and control algorithms in a safe setting. The HiL capabilities of this simulator will be extended with an interface towards high-performance embedded supercomputers, and will serve as a baseline tool for software development in the project.

TESTING

Development for this kind of application requires the setup of an efficient **continuous integration and continuous deployment** pipeline. The partners in the consortium have gained experience in this regard and have developed internally solutions to automate unit testing, integration testing, system level testing and software-in-the-loop testing. To this purpose, several simulation solutions are available internally in the team.
Moreover, each module will provide **diagnostic information** for continuous monitoring of car operativity and safety. The ability to replay offline previous runs, both for debugging or performance analysis (at the computational and race level) will be essential.
It is foreseen that the team vehicle will be hosted in UNIMORE facilities, which guarantees access to testing tracks and areas.

PROJECT MANAGEMENT

The whole project will involve senior and junior contributors from each partner.
Team organization will consist of a team leader, a team manager, a scientific board and departments such as vehicle dynamics, vehicle maintenance, system architecture, system integration, SLAM, motion planning, prediction, simulation, management, communication.
Each department will identify one responsible who will guarantee participation to sprint planning meetings and will directly interface with the team manager and leader. The goal is to organize work in periodic sprints, with clear goals identified and agreed beforehand by all participants. Progress will be measured with relevant Key Performance Indicators identified in the first phases of the project and in collaboration with Indy Autonomous organizers.
At the end of each sprint, one or more deliverables are expected, which might be reports on the design choices, software deliverables, video or social media material, or others.

The inspiring principle for communication of EURORACING's work is to go public as soon as possible with results, efforts, issues, to promote engagement in the initiative and disseminate autonomous driving insights to the research, industry and the general public. This goes in the direction of one of the main goals of Indy Autonomous Challenge: "*Engage the public to help ensure acceptance and use of AV technologies*".

[1] HiL simulation enables the design, development and validation of complex control algorithms directly in the final production hardware at early stages

FUNDRAISING

Each team will fund their members' work independently. In particular, the funding available at each institution, or by means of regional and European funds, will be adopted. Private sponsorships will be encouraged from commercial partners to guarantee financial coverage and promote engagement of autonomous driving stakeholders such as Tier 1, OEMs or automakers. As an example, UNIMORE will engage local industrial partners, such as Ferrari, Maserati and Dallara, which already expressed an interest in following the activities related to the Indy Autonomous Driving Challenge.

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