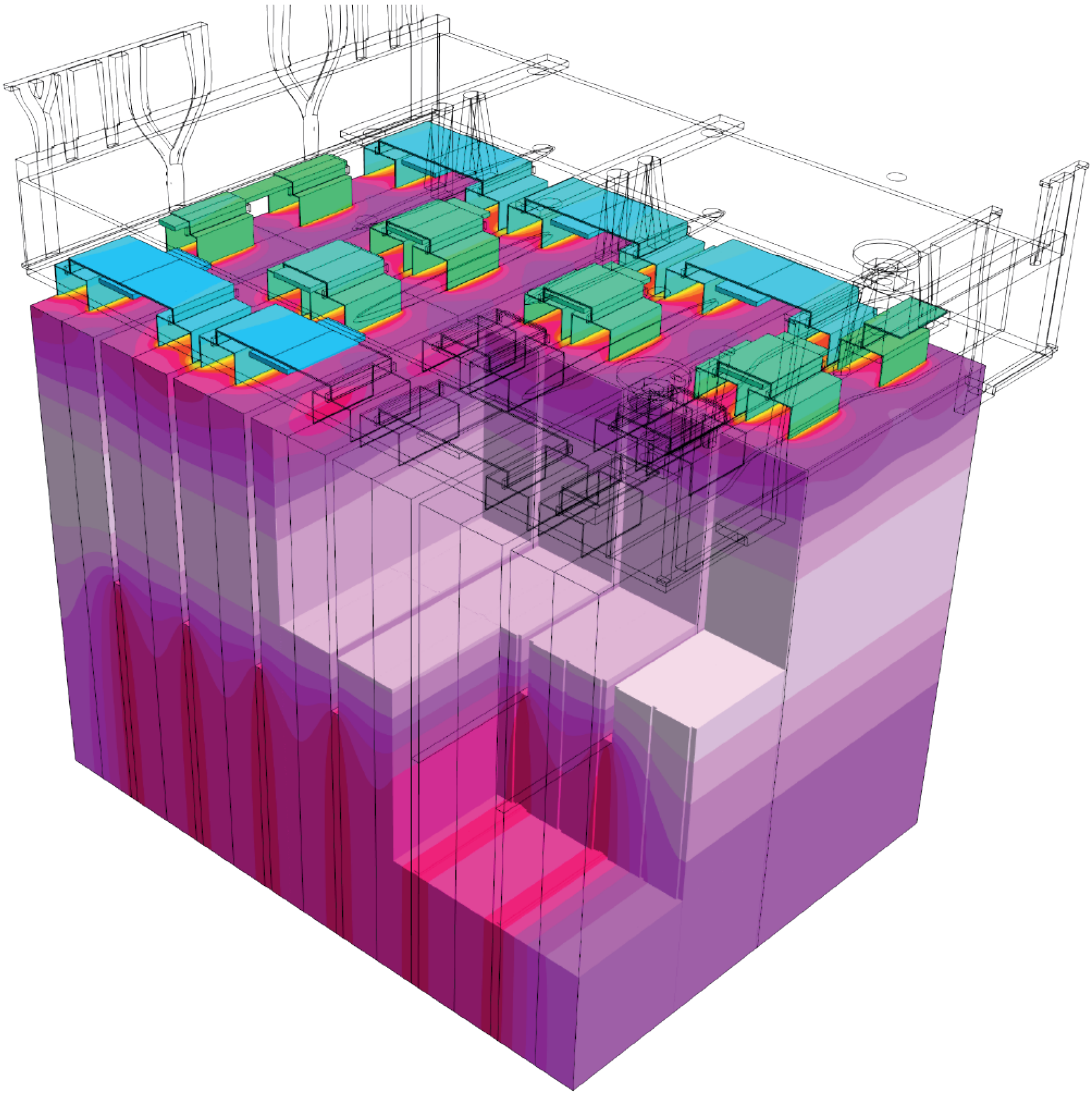
FSTLISBOA | MAY 2020

THE DESIGN MAGAZINE

NEW SELECTED FEATURES ELECTRIC & DRIVERLESS



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Editorial

Dear Reader,

As its title implies, this year's first out of two issues is purely focused on some of what were the design improvements entering this new generation of prototypes.

Having said that, I would like to reassure you that this is not meant for high profile engineers in any way (in case you were thinking about switching to a lighter read already).

The all purpose of writing a magazine like this one is to involve you on the team's technical breakthroughs, whether you have advanced knowledge on these fields of expertise, or you're simply just curious.

Either way, you will find that the magazine has two front covers, rather than just one, dedicated to both driverless and electric projects.

You will also find that there's black and white pages to visually differentiate the articles about FST 10d and FST 10e, respectively, and a glossary to help you with some of the technical abbreviations used throughout the DV section.

Being the debut season of FST Lisboa as a team working simultaneously on two race cars, these have been, unarguably, changing times. We have established ambitious goals not only for our prototypes but also in terms of the way we perform our daily tasks in order to potentiate our delivery.

So, without further ado, I will leave you to explore what deepens our desire to step on those iconic tracks every year, and experience the thrilling world of Formula Student.

Enjoy!

Written by Maria Carolina Barata
Marketing Manager

Editor-in-Chief:

Maria Carolina Barata

Graphic Design:

Maria Carolina Barata

With Reviews from:

Inês Netto de Viveiros
João Pinho
Mariana Sequeira
Mariana Vieira
Beatriz Lopes

Special Acknowledgments:

Marta Canário, Novabase
Joana Prazeres,
Savannah Resources Plc

Generation 10

The first time that someone heard about Formula Student at Instituto Superior Técnico was when a group of 5 mechanical engineering students founded *Projecto FST (Formula Student Técnico)* back in 2001.

Since then, this group of students, that grows and is renewed each year, has been an active contributor to the portuguese engineering *playground* by developing the first portuguese electric race car (*FST 04e*) in 2011, the first carbon fibre monocoque chassis in 2013 (*FST 05e*), and now, nineteen years later, with *a bound to go down in history* pair of prototypes - *the Generation 10*.

During the present season, the team has been committed to developing autonomous driving systems in order to upgrade the previous year's prototype *(FST 09e) into FST 10d* - the first autonomous car *Made in Portugal*. Thus, the team would with two prototypes in two different categories: *electric and driverless (autono - mous)*.

With a heavy legacy to which last year's prototype largely contributed by being the most reliable and fastest car to date, and by being ninthat FSG, when it comes to EV class, FST 10e aims to *beat its ancestor's performance* - just how the healthy rivalry between the team's different generations implies.

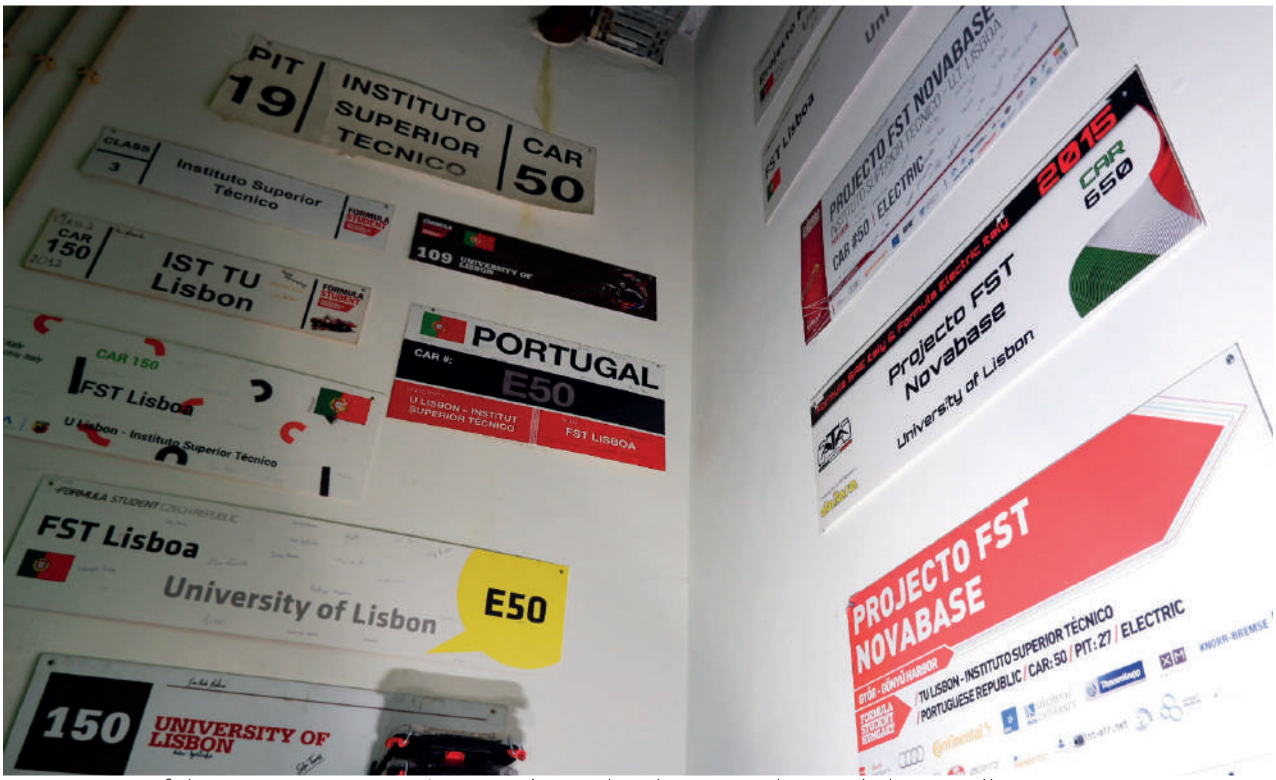


Fig1. Some of the competition pits' nameplates that hang on the workshop walls.

As for the FST 10d, that appears without any internal rivals to beat, the goal is to be able to score in all events, regardless of the speed at which it does so, allowing the validation of the team that will now be part of this new industry.

With that in mind, and besides all the efforts taken to design the prototypes, the team also spent several months preparing for the registration quizzes, where it ended up qualifying for all the competitions including for *Formula Student Austria* that takes place in the Red Bull Ring and gathers some of the best teams worldwide - another first on FST Lisboa history.

As expected, competitions play a major role on the growth of any team for they are the perfect occasion to validate all the work that was done, even more so when they allow the sharing of knowledge and culture between teams as well as the direct contact between them and high profile engineers from top companies in the industry.

However, the season that promised to be full of debuts from its first second on, now presents itself as an even greater challenge. Like other sporting events that would take place in the summer of 2020, Formula Student competitions were also, one by one, canceled in a collective effort to ensure public health and safety conditions at a time when the situation is critical all over the world.

At the same time, FST Lisboa interrupted the work at the workshop and is now focused on what can be done respecting social distancing.

Yes, the reality of what is happening in the world is much greater than us as individuals, than the team, than any competition or than the entire Formula Student community. However, FST Lisboa is committed to maintaining the same level of commitment and dedication that it has shown since the beginning of the year, so that, in a brighter future, we can all look at this season and at the team as a case of success that, despite all adversities, did what was planned!

Written by Inês Netto de Viveiros
Team Captain for FST Lisboa

A Formula Student Year in a Nutshell

- What to take into account when planning a season

A Formula Student project is not your conventional project.

Being of the entire responsibility of uni students, depending on multiple sponsorships, and being limited to a 10 month working period, makes developing race car prototypes an unique project.

In the beginning of the season, the team sets its goals and the requirements in which they're translated. These will serve as the basis for defining feasible and measurable tasks to which the right resources will then be allocated.

There must be a definition of tasks or work packages which make up the *WBS* for the project. The definition of this packages inherently defines the scope of each of the team's departments. In order to properly and realistically define each department's scope, there has to be consideration for the available time (limited by the date of the first competition) and for the work proposed by each of the department's responsible and technical director, which provide a greater insight into the work ahead.

It's on these grounds that the project's timeline is created which, in its turn, makes both forecasting of needs and defining which tasks constitute the critical path easier.

But what exactly is the critical path?

According to the Project Management Institute's *PMBOK*, a project's critical path is *the sequence of tasks which directly influences the projects duration.* Thus, its analysis is essential to establish priorities and meet deadlines.

The season is then divided in five sequential work stages according to their different objectives: define general objectives for the various subsystems - *Concept Stage;* design a functional and competitive car - *Design Stage*; fabricate or have it fabricated by sponsors - *Manufacturing Stage*; test the developed car to identify problems, correct the problems and learn how to tune the car - *Test Stage*; and transport the car and the equipment necessary for its maintenance to a foreign country to attend some of the biggest engineering competitions in the world - *Competition Stage*.

Since, at first, both budget and available resources aren't fully known, and even considering previous years' documentation, the risk associated to this project is always high and to guarantee its success has a lot to do with being able to control those risk factors.

Despite the unexpected nature of some variables such as the COVID-19 pandemic we're facing, a lot of the risk inducers can be predicted and mitigated as was the case of the car's transmission system that, historically, has been troublesome. To avoid so as much as possible, actions like manufacturing 1.5x the whole system and treatment procedures have been included on the planning.

All this makes knowledge on project management extremely important for the team's efficiency levels as is the reason why there has been an increasing investment on tools to help manage engineering projects.

Written by Miguel Rodrigues
Project Manager for the FST 10e

Defining Goals

Written by Ricardo Crespo
Head of Vehicle Dynamics

Vehicle Dynamics is the area that quantitatively translates the conceptualization that is done at the beginning of the season. This year, several initial simulations were carried out in order to convert the car's initial performance objectives into objectives for each system.

These simulations were made using a time lap simulator that represents the car as a rigid body without rotation (zero resulting torque) to which Newton's Laws apply. This type of simulation considers that the car always behaves at its performance limit. Although we were unable to determine an accurate best time lap on a given track, we managed to acknowledge the influence of several general parameters on both longitudinal and lateral performances.The parameters we were able to study are as listed:

- Mass- Aerodynamics(CL, CD, front area)
- Tires (longitudinal and lateral friction coefficients, rolling resistance, radius)
- Rotational Inertia
- Motor efficiency map and torque curves by speed
- Battery power and regeneration

To rectify the influence and study combinations of optimal parameters, we performed sen-sitivity analyzes such as the following which objective was to study the influence of the car's aerodynamic parameters on the overall score of a Formula Student competition:

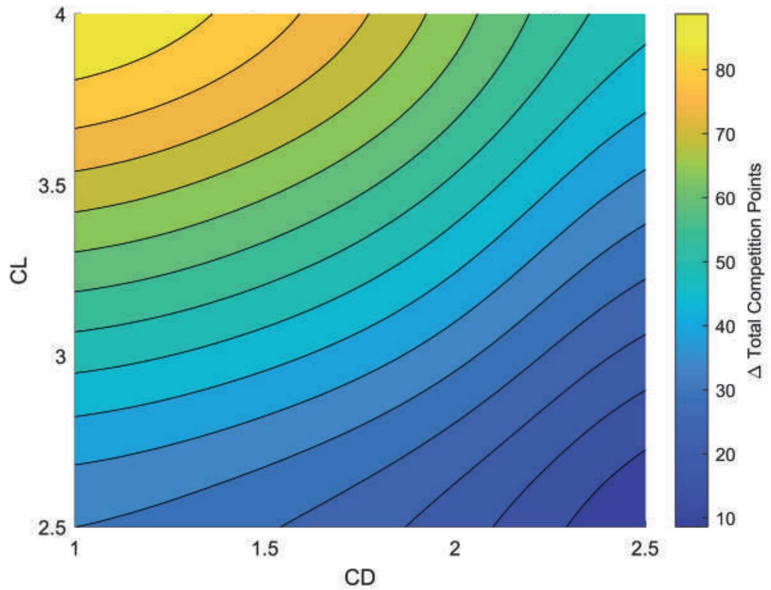


Fig2. Total Competition Points Dependence on CDrag and CLift

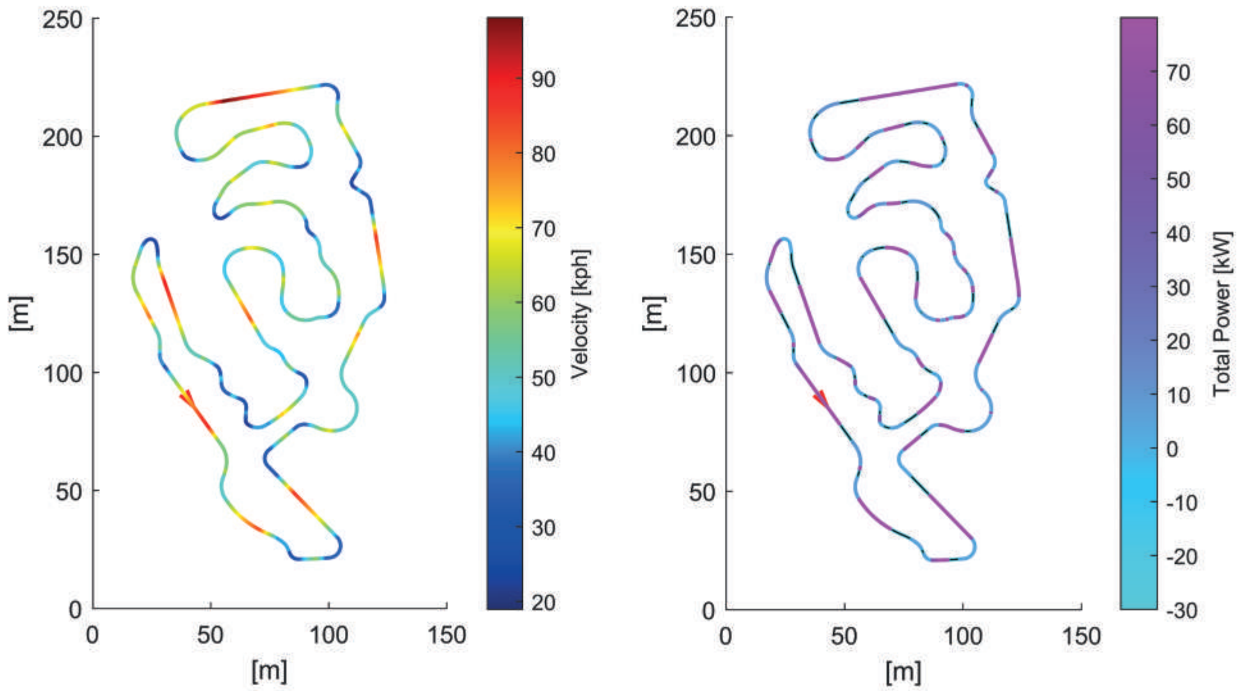


Fig3. Velocity of the car and total power delivered by the motors on each segment of the track, respectively

Likewise, and using values from previous cars and superimposing data, we were able to determine accelerations, speeds and instantaneous powers that allowed us, for example, to withdraw data necessary to study power input and output power from the battery and system use cycles.

Using this same tool we were able to establish the lateral and longitudinal performance objectives of the car, and determine how much the team could achieve in a Formula Student race similar to last year's.

Starting from these objectives we deconstruct to others more specific to each system. Throughout the Design season, data from new simulations was iterated and analyzed to ensure that what is being done will fulfill the car's performance objectives.

The Pedalbox

Written by Pedro Neves
Head of Chassis

Every car is necessarily equipped with a system to convert a small amount of energy exerted by the driver into braking and accelerating the motor vehicle.

The system that allows this driver/car interaction is called the *pedalbox* and it contains a working brake and throttle.

As it is known, when designing any system of a formula student prototype there are constraints and requirements that must be met in order to pass scrutineering and compete.Thus every modification should be cautiously deliberated as sometimes what seems like a great improvement might end up not being implementable, specially when speaking of a system that holds relations with multiple systems including the car chassis, braking system, and accelerator system.

Other aspect that should be kept in mind during this particular design process is that *Ergonomy is key*: the pedalbox needs to be comfortable and adjustable to suit different driver's needs, with adjustable pedal ratio and angle with the floor of the car, for instance. In addition, the driver's trust in the pedalbox functional ability must be considered as a driver feeling tentative on the brake or accelerator would decrease performance results.

Based on these permisses, these were the major differences introduced in the FST 10e pedalbox system:

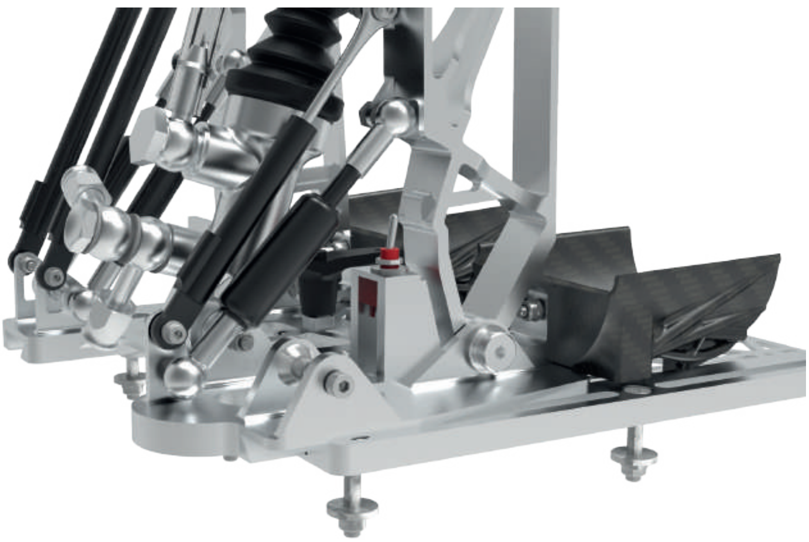


Fig4. Enlarged Brake Trail and the new BOTS + stopper assembly

Fig5. Travel Recovery System

1. Increasing the thickness of the connecting fins between the base and the pedals & Lowering the connection point between them

This allows a decrease in stresses applied on the pedal's base and eliminate the lateral compliance in excess that otherwise will result on incorrect reading on potentiometers and unwanted deformations.

2. Widening the rail under the master cylinders

Which will increase the creep resistance and prevent from excessive deformation at the base when pressing hard on the brake pedal.

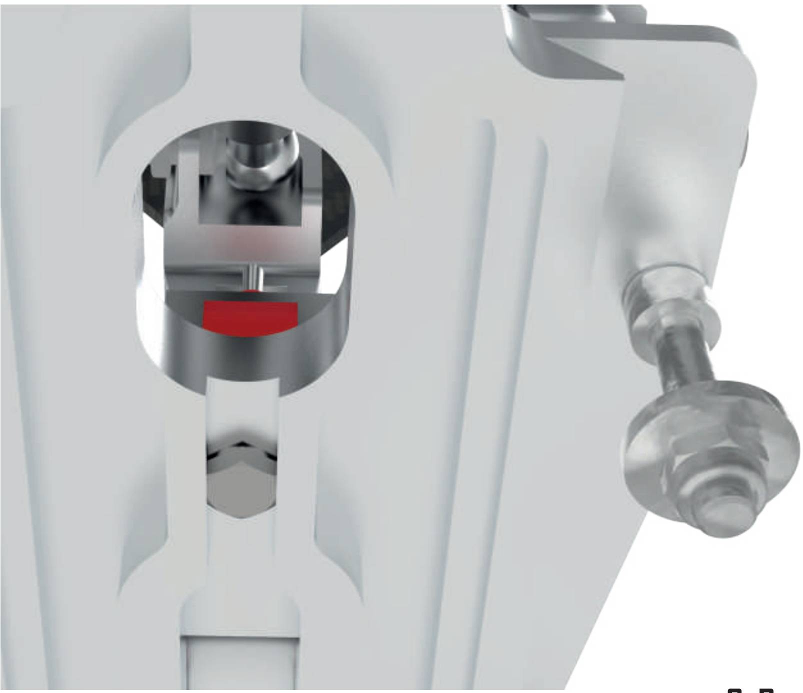


Fig6. Attachment Bolt for the stopper

3. Implementing a slot system with free movement

So that the mechanical spring used could now be parallel to the master cylinders and that mechanical and electrical braking could be separated.

4. Braking Pedal Redimensioning

In order to easily activate the BOTS (Brake Over Travel Switch). The former pedal's profile hindered its activation even with no pressure in the brake line.

5. Switching from pickup points to elbow joints on the throttle springs

To prevent excessive clamping and allowing small rotations without affecting their functioning.

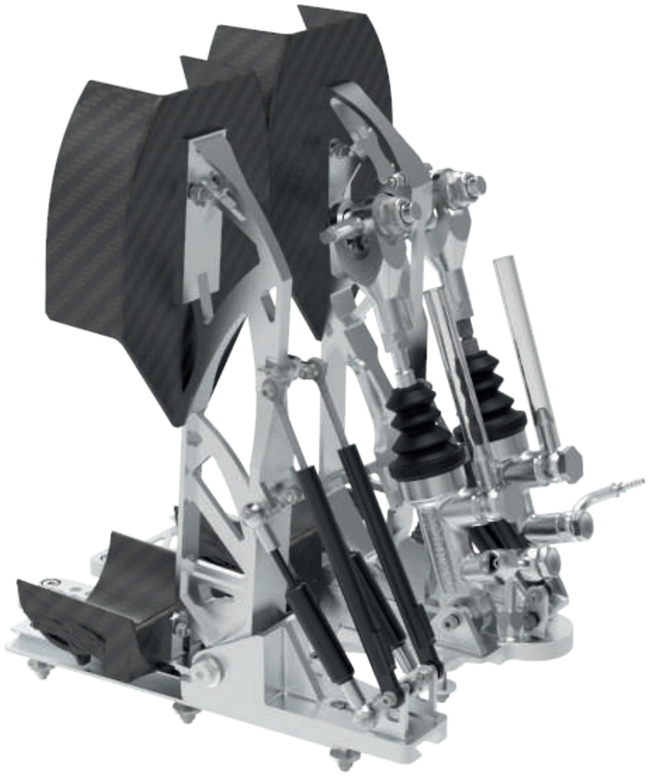


Fig7. Complete Pedalbox Assembly

6. Resizing the throttle stopper

By increasing its overall dimension, which will reduce the stresses on the pedal and consequently excessive deformation from happening.

7. Using a Hex Screw on Brake Stopper

Having a positive locking system with the pedalbox base design, this will allow the brake Stopper disassemble or adjustment without removing the entire pedalbox out of the car.

8. Cutting Edges

Bases and rails are both triangular in shape and cutting their edges will prevent them from inducing excessive friction by enable a greater slip between parts.

The Wind Around Our Wings

Computational fluid dynamics, simply referred to as CFD is no news for the aerodynamic department. In fact, this branch of fluid mechanic analysis is essential to the right modelling and design, since it allows a better understanding on the behaviour of the air that flows around a car.

During a dynamic event, the car is going through corners most of the time, so performing flow analy- sis on both curve and straight trajectories is extremely useful.

To better respond to this need, CFD simulations have been fully automated by developing a script (MACROS) that repairs geometry, generates mesh, runs simulations and post-processing whether the car is turning or going straight forward.

The use of these macros allowed a faster design process, since configuration is now automatic and the possibility of user errors is close to none. It was also possible to carry out numerous simulations with the same conditions and images directly comparable with other studies which proved to be quite useful for drawing conclusions.

As a result, changes were made specially on the front wing and side elements' design that create and control vortices meant to alter the flow as desired and intensify desirable air flow features along the car.

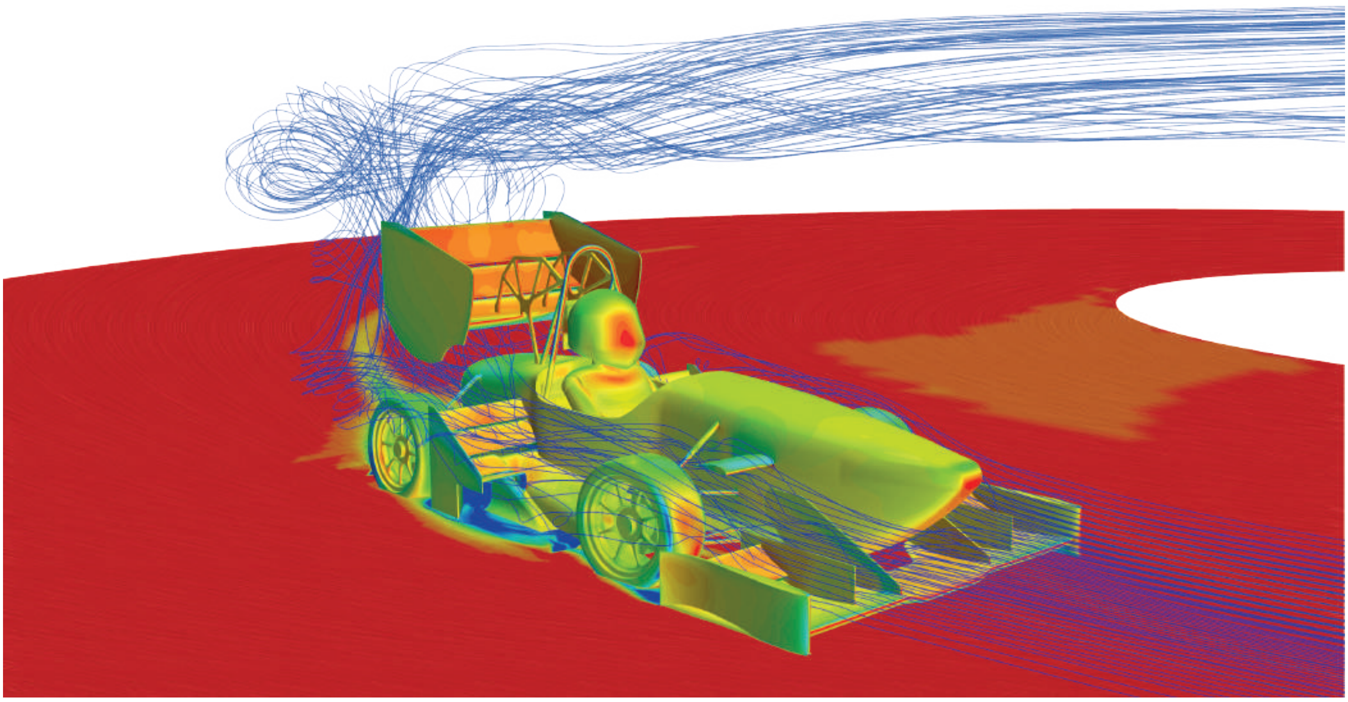


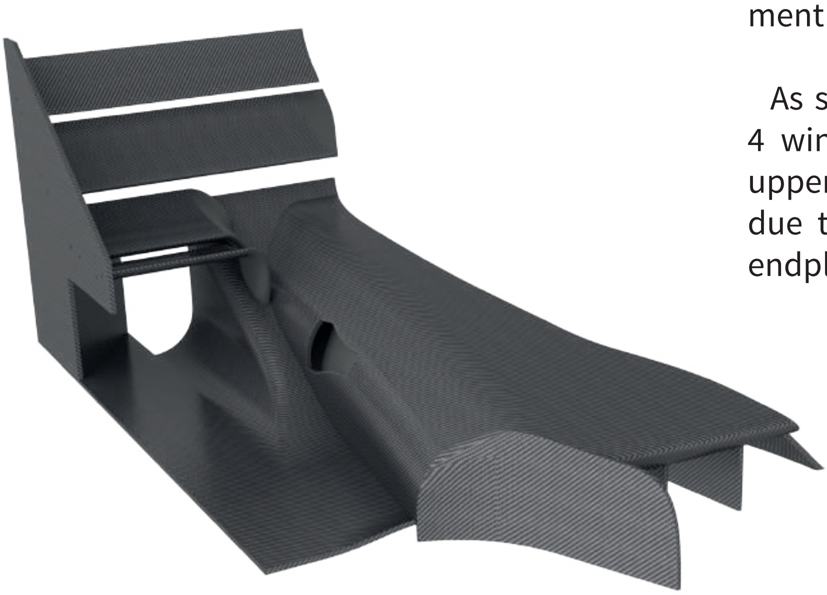
Fig8. Cornering CFD Simulation

Side Elements

These parts went through major design changes, since radiators are positioned at the rear on the FST 10e. Due to this change, the side of the prototype has now a larger space that can be used for aerodynamic improvement.

As seen on the left, side elements consist of 4 wings positioned next to the pilot. The 2 upper wings that are connected to the monodue to regulation restrictions working as an endplate.

Fig9. Side elements on the FST 10e



Written by Miguel Carreira
CFD Analyst

Front Wing

Despite keeping its general shape, some of the flaps present on the FST 09e part were removed to provide clean air to the side of the car. The efforts were put into redesigning the front wing endplate. Due to its profile shape, the part is now suitable on both straight and curve scenarios.

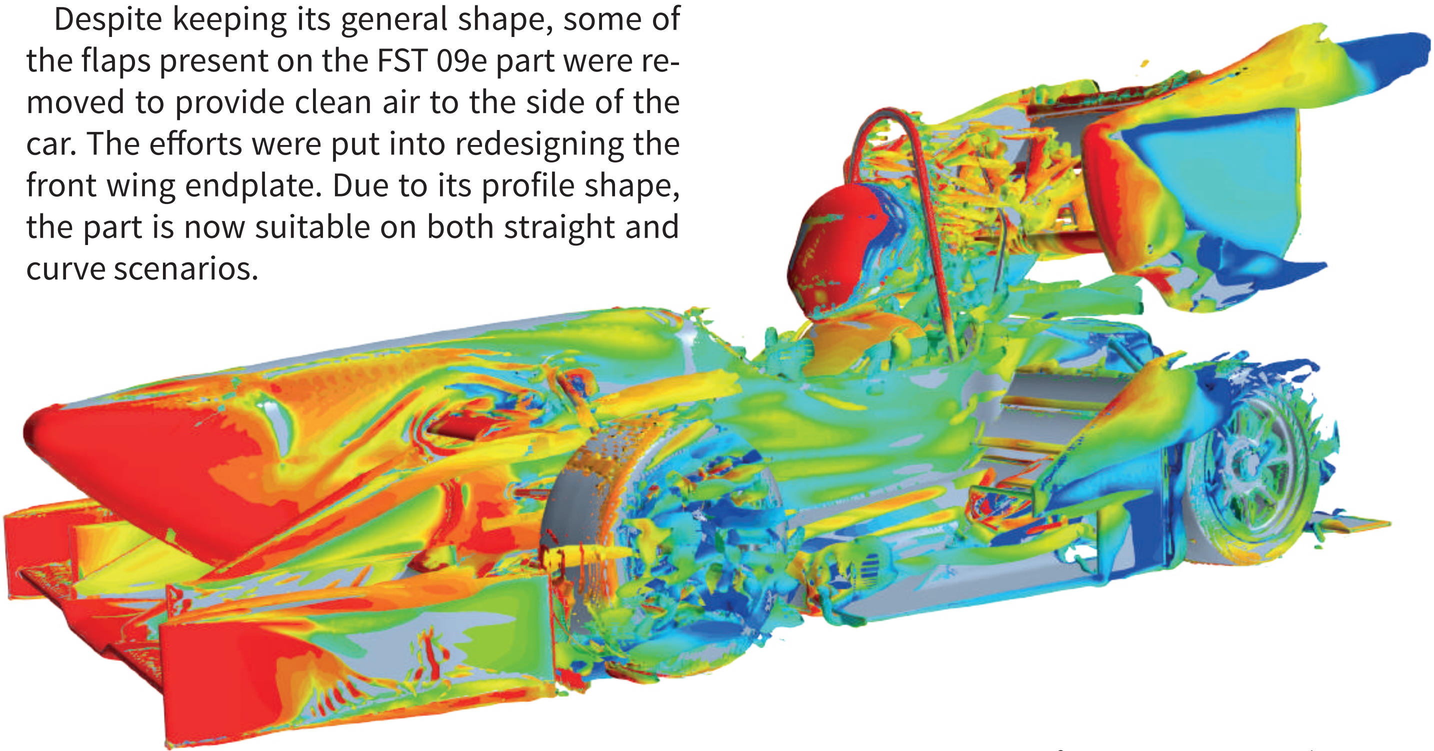


Fig10. Q criterion isosurface in a corner condition

Despite the head start given by the FST 09e, the overall weight of the car and the high temperatures of its accumulator cells, which almost compromised the Endurance at Circuit de Barcelona-Catalunya (FS Spain), motivated the Powertrain members to define the entire cooling system, overall accessibility and weight reduction as their design priorities.

Amongst the various parts contained in the powertrain package, the accumulator was the component that underwent more changes, distancing itself in several aspects from its predecessor.

In order to make the competition safer and more equitable between teams, accumulators are one of the most regulated components in a Formula Student car. For this reason, the implementation of the new concepts proved challenging from the start.

One of the innovations set in motion during the design stage was the use of composite materials in the manufacture of the accumulator container, where the cells are accommodated in various groups called stacks.

Roaring Up At Full Trottle

The current path has been rethought to allow for the desired changes. The team chose new cells, with higher energy density and less energy dissipation, in order to reduce both the total weight of the accumulator and facilitate thermal management.

A new electrical configuration of the different stacks with 14 cell in series and 1 cell in parallel, allowed not only to improve accessibility for the necessary maintenance inside the accumulator, but also a reduction of the overall weight of the system by a decrease in amount of cables and conectores

In such way, and after an intensive analysis of the data collected last year, the team decided to reduce the total energy of the accumulator by about 0.5 kWh, about 6% of the total energy, significantly reducing the total weight of the system.

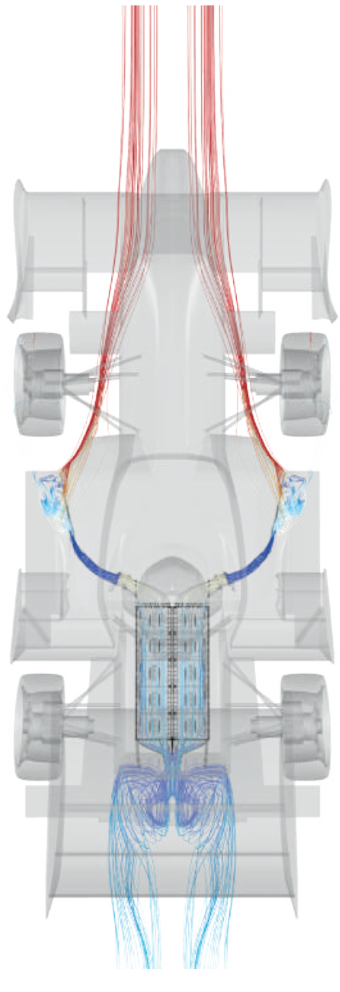


Fig11. Accumulator air flow total pressure

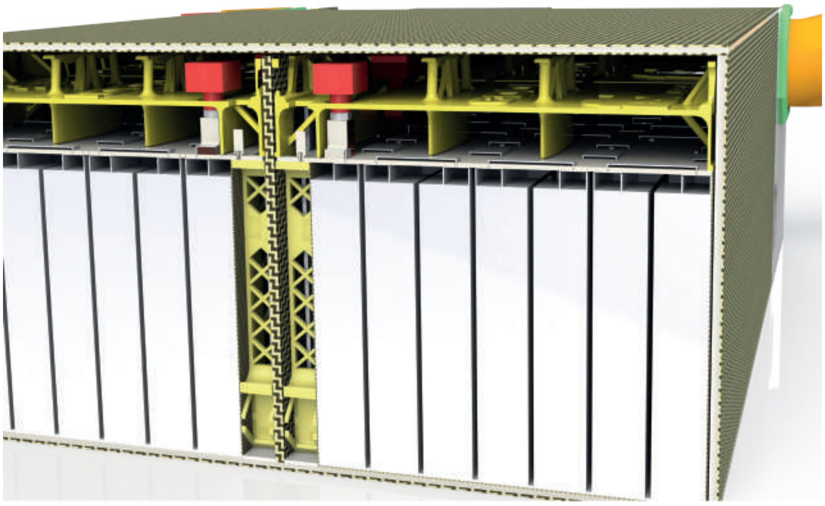


Fig12. Accumulator stackroof

Written by Miguel Santos
Cooling System Designer

Simplifying the current path also allowed a new cell cooling method: an air corridor has been created at the top of the cells, where they release the heat generated.

To achieve better performance and a more uniform temperature distribution in the cell body, small amounts of PCM (phase change material) were placed between the different cells' bodies. PCM is a material that allows the absorption of large amounts of heat during phase change from solid to liquid, without it translating into an increase in its temperature.

The cooling strategy involves rejecting the heat to the outside using the previously mentioned air circulating inside the accumulator, maintaining an ideal cell operating temperature (50ºC). After becoming liquid during prolonged use, it is necessary to allow time for the PCM to release all the heat it has stored. Only then will the cooling capacity be at its fullest.

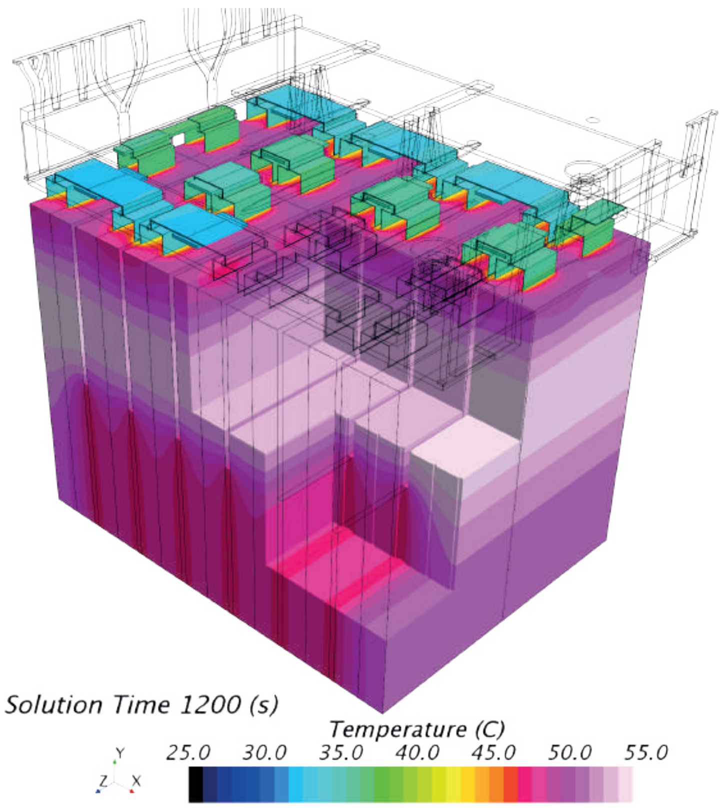


Fig13. Stack Temperature

The Sponsor Check: SAVANNAH

Who We Are

Savannah is a mining prospecting and development company, with a portfolio of assets that are distributed between Oman (copper), Mozambique (mineral sands) and, since May 2017, Portugal (lithium).

With highly specialized staff, solid principles and efficient management, the company developed in Mina do Barroso the largest litiniferous resource in Europe, which allows us to be the first lithium producer in Europe.

Solid Principles

Savannah is commited to establish a partnership with communities based on three fundamental pillars: commitment, transparency and honesty.

We want to grow the business by acting responsibly in the communities, minimizing the impacts of our activity. It does not make sense for Savannah to build a mining project if not linked with an improvement in the quality of life in the surrounding communities.

It is based on this principle that we dedicate great attention and investment in different engineering and environmental projects, and in performing environmental and socio-economic impact studies in the regions where we operate.

In addition, we put in greatest efforts to boost local dynamics, supporting communities, associations and entities that contribute effectively to the community.

All of our mining prospecting activity is audited, clear and available to communities with whom we share all results, such as measurements of noise, dust or water levels and quality. All of this in a transparent way and with maximum responsibility.

At the base of our work are people and communities.

[1]Mina do Barroso, Portugal as background image of this article.

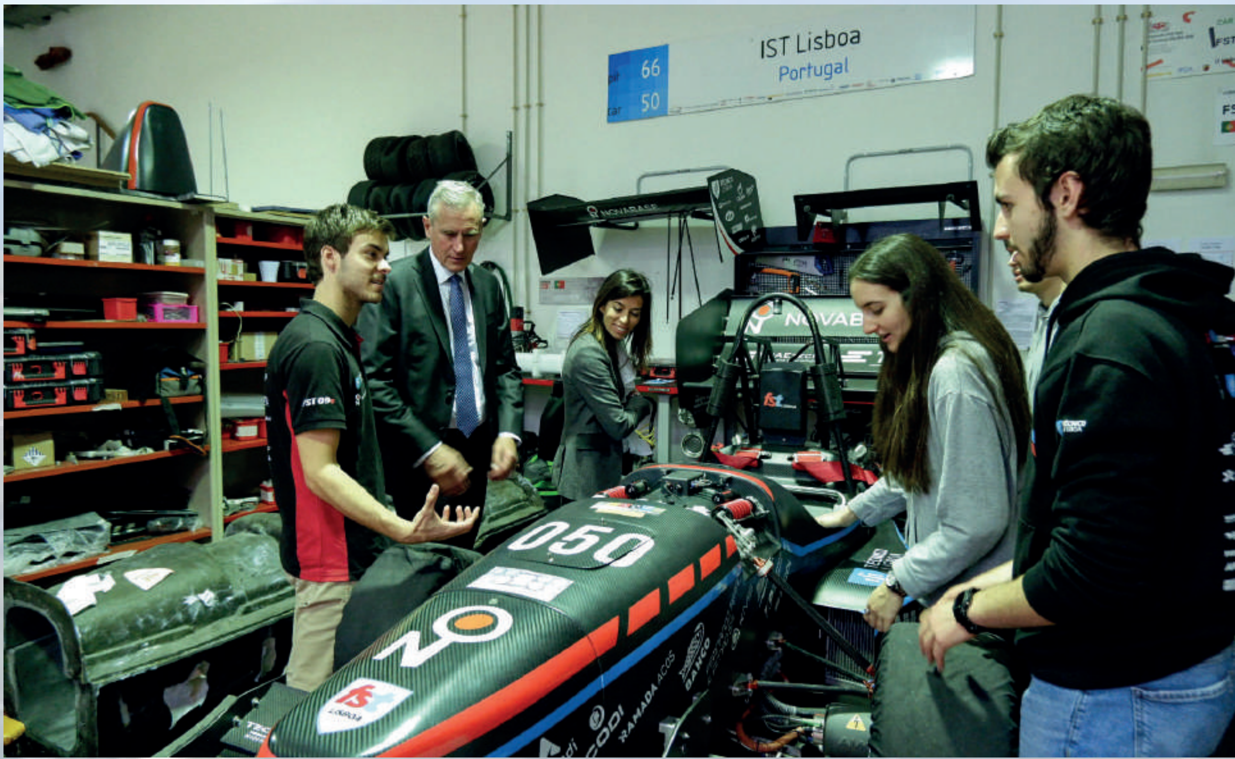


Fig14. CEO David Archer & Head of Communication and Community Affairs Joana Prazeres visiting the team's workshop back in October 2019

Relevance in Portugal: Lithium prospecting

Savannah's exploration activities in Portugal are focused on lithium research. A silvery and soft metal that, in its natural state, does not appear in simple substances, but rather associated with other elements. Lithium and its chemical compounds have a wide variety of applications, including glass, ceramics, and batteries. The market for lithium batteries is the fastest growing.

The importance of lithium has increased in recent years, since it is a key metal in the composition of lithium batteries, which, due to their application in electric vehicles, gain relevance in the strategy of reducing greenhouse gas emissions. It is in this context that lithium becomes essential in meeting the goals regarding climate change.

In Portugal, Savannah plans to extract spodumene concentrates from Mina do Barroso, a mineral that is later converted into lithium.

Spodumene is selectively extracted from pegmatite to produce a concentrate with 6 to 7% $Li2O$ content that will produce lithium hydroxide or carbonate with 75 to 90% Li content for battery manufacture. To concentrate spodumene to the required levels, a simple crushing, grinding process is necessary, followed by a selective flotation process before the concentrate produced is transported for sale and further refining in lithium hydroxide or carbonate in other countries, since the Europe has not yet installed this capacity.

The ore produced annually by Mina do Barroso can be used to power more than 600,000 city electric vehicles.

Drivetrain Optimization: The Upright

The upright is a vital part in every race car due to its multiple functions and interactions. As in previous prototypes, the featured upright houses the transmission and hub, as well as it holds the electric motor of the car, making it the central component of the drive train system. It is also responsible for supporting the brake calipers and connecting the drive train assembly to the suspension rods while withstanding the loads of the contact patch.

Following the general philosophy for the FST10e, with the focus of correcting the previous year's flaws, the main features to improve were the excessive weight and friction, originated by the components that integrate the upright. The latter enhances an adverse environment for the drive train to work properly, ultimately leading to the unpleasant competition-wrecking oil leaks.

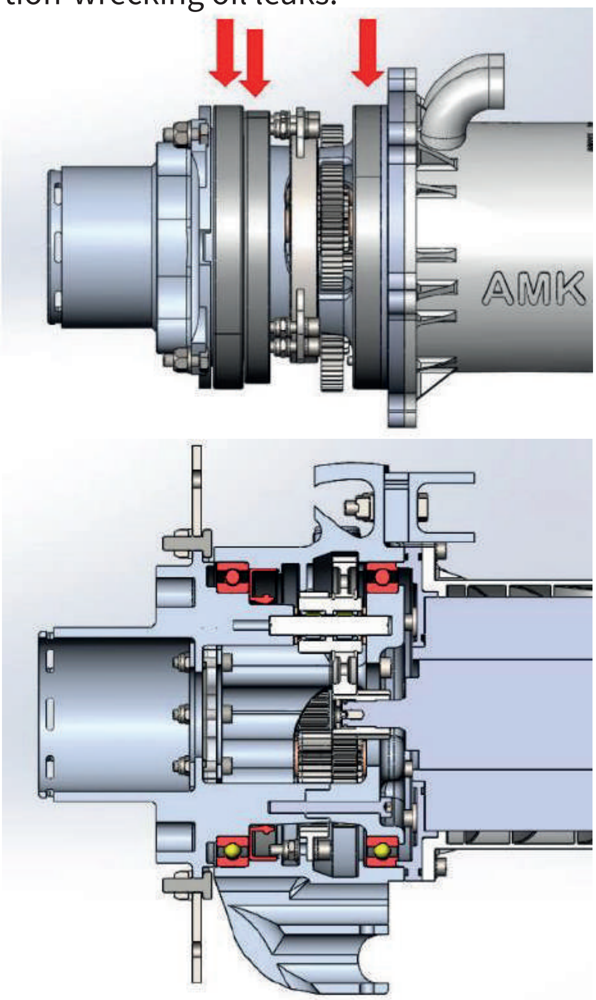


Fig15. Drivetrain Assembly

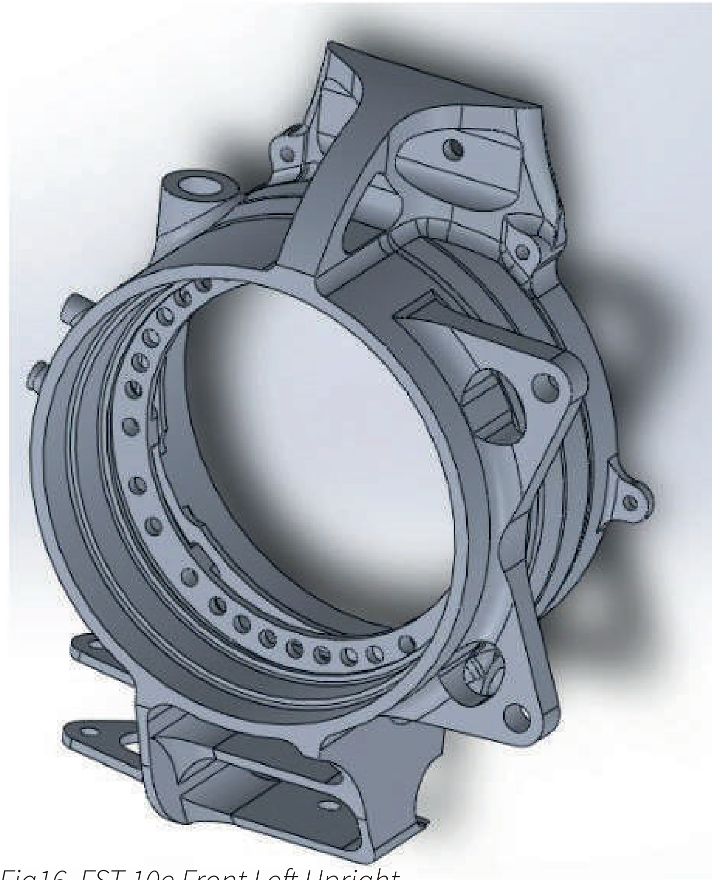


Fig16. FST 10e Front Left Upright

Initial Constraints

Suspension Geometry

Similarly to the previous prototypes, a double wishbone is featured in the FST 10e. The upper wishbone and the push rod connect to the upright via what we call the camber support, since it's the point where the camber angle of the car is adjusted, while the lower wishbone and the tie rod (or toe link, in case of the rear of the car) are directly bolted to the upright.

Planetary Transmission

The upright must feature a secure way to fix the outer ring, and have a min. 1,5 mm distance from all moving parts in the transmission assembly.

Hub, Bearings & Retainer

The upright must house two bearings of 125 mm exterior diameter and an oil retainer of 120 mm which predetermine the interior dimensions of the upright.

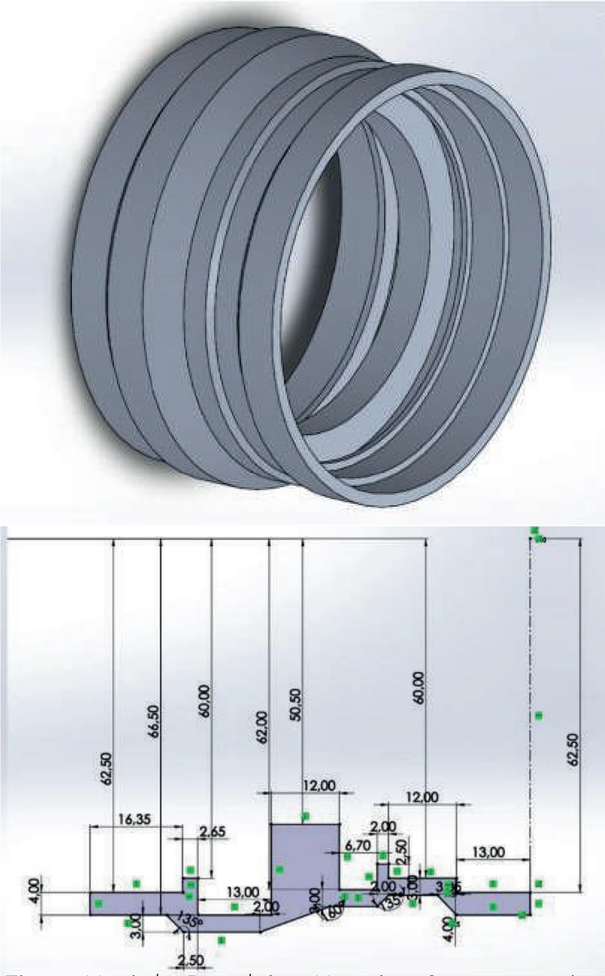


Fig17. Upright Revolving Housing & cross section

As a starting point, a revolved solid was created, in compliance with all the necessary interior diameters and lengths. This included the dimension retainer, transmission and its fasteners.

Following this first step, the upper and lower supports of the upright were added, with the results of the topology optimization having a major role from here on.

Given these results, for the upper upright support, the obtained geometry was replicated as closely as possible. Due to machinability limitations, some small adjustments had to be done in order to simplify the geometry.

The FST10e lower upright support maintains a similar design to the one of FST 09e. However, its lateral walls were made parallel due to the excessive and unnecessary bulk of the precursor, achieving a smaller and lighter solution.

This way, a smaller and lighter solution was achieved.

With the purpose of measuring the temperature of the upright and brake disc, three equidistant protruding supports were added for this year's upright. Each of these has a hole for an M4 bolt, which together, will allow to fix a PCB.

Given the success in the implementation of a magnetic drain plug in the FST09e, the same general system transited to the FST10e. The strategic placement of the drain plug, tangent to the oil flow, aims to maximize its function, resulting in a minimum of steel debris present in the transmission oil.

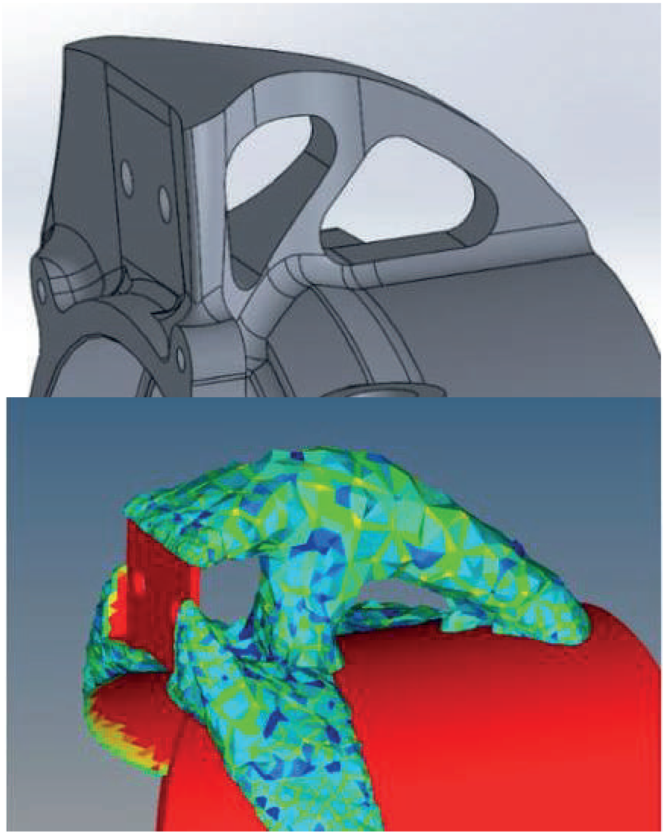


Fig18. Upper Support Optimization and CAD model

Written by Manuel Ferreira
Hub & Upright Designer

Test Bench Introduction

The Electronics development process has three main phases, *Hardware design*, *Software development*, and *Testing.* This year, a new testbench was introduced to improve testing standards and reduce the time between design iterations. Ensuring the overall system stability and high performance our architecture is known for.

Being the main hub for the electronics development, where all electronics members work on a daily basis, a lot could be said regarding its inner-workings.

In a brief explanation, the main innovation was simply having a test bench the whole year round. This enabled us to have a *working* car whenever needed. Since most of the Electronics systems are on the testbench, all the car's electronic systems can be tested and simply swapped when a new version is developed.

Other specific innovations were also developed such as interconnection with the Motor's test bench, allowing testing with the high voltage powertrain.

Simple things such as the standardization of connections, allowing faster removal and replacement of systems, and the integration of real sensor inputs allows the development and testing of most systems to which cooling control where real fans and NTC thermometers were added to the testbench or pedal acquisition with sliding potentiometers are examples.

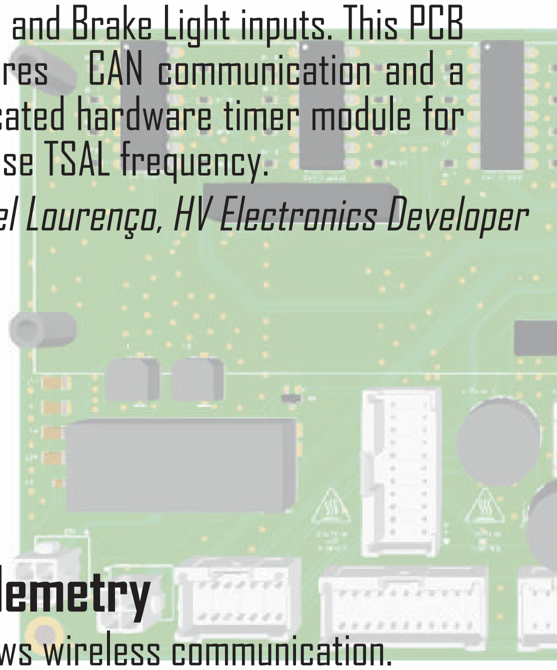
Having daveloped more than 20 pcb's for each FST prototype, here are some that never leave our test bench:

Written by João Ruas
Head of Electronics

DCU- Distribution Control Unit

Responsible for power distribution and signal routing to the Low Voltage subsystems. Partial Shutdown Circuit control and detection are some of its extra functionalities. It controls TSAL, RTDS and Brake Light inputs. This PCB features CAN communication and a dedicated hardware timer module for precise TSAL frequency.

Miguel Lourenço, HV Electronics Developer

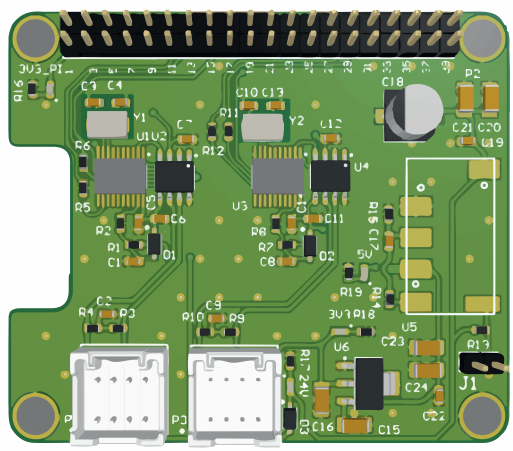


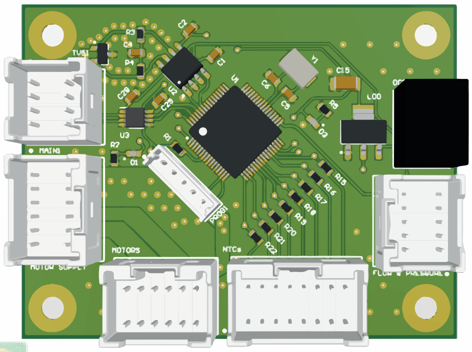
Telemetry

Allows wireless communication.

Transmited data consists on the CAN Bus messages being sent continously between the electronic systems. The data can be analysed resorting to the in house developed Interface, and is specially important to obtain information while the car is racing.

Filipe Oliveira, LV Electronics Developer

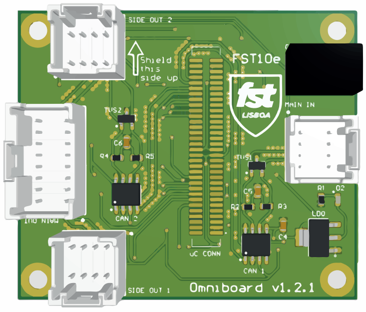




CCU- Cooling Control Unit

Responsible for activating pumps & fans, as well as for collecting data on car temperature, pressure and flow on the cooling circuit.

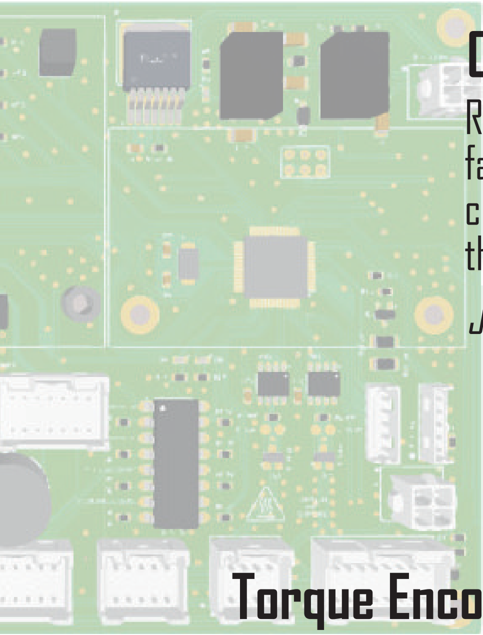
José Pereira, LV Electronics Developer



Omniboard

Collects data from suspension sensors and communcates with the WSU (Wheel Sensor Unit).
To allow the experiment with new microcontroller architectures, these component-can be easily changed.

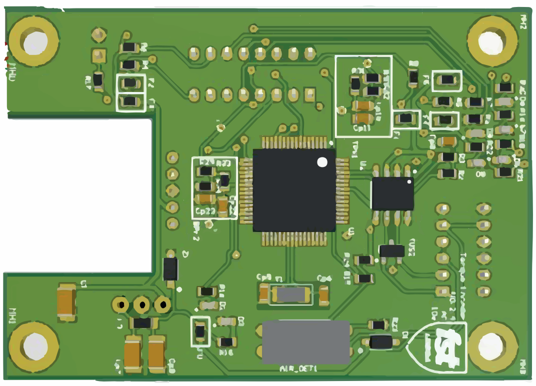
José Pereira



Torque Encoder

Pedal Box Sensors aquisition.
Outputs the pedal positions (Brake & Throttle) and does implausibility checks, such as short-circuited sensors, different output values from the same pedal, broken wire, etc. It also checks the state of the shutdown circuit between the motors interlock and the BOTS.

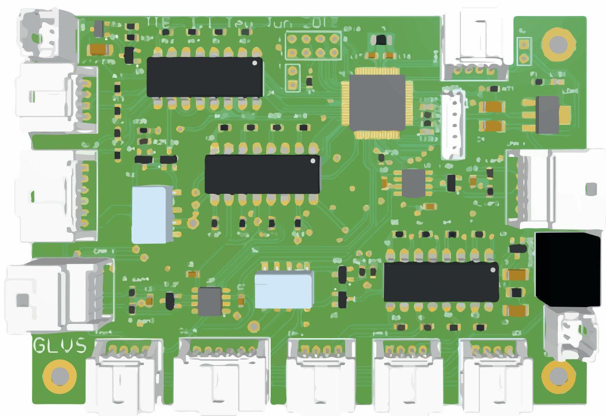
André Correia, LV Electronics Developer



IIB-Inverter Interface Board

Communication between the car and the inverters.
It also acts as a low level controller, first ensuring safety, and then by implementing different deratings to protect motors and inverters, as well as simple algorithms such as a power limiter or a differential controller.

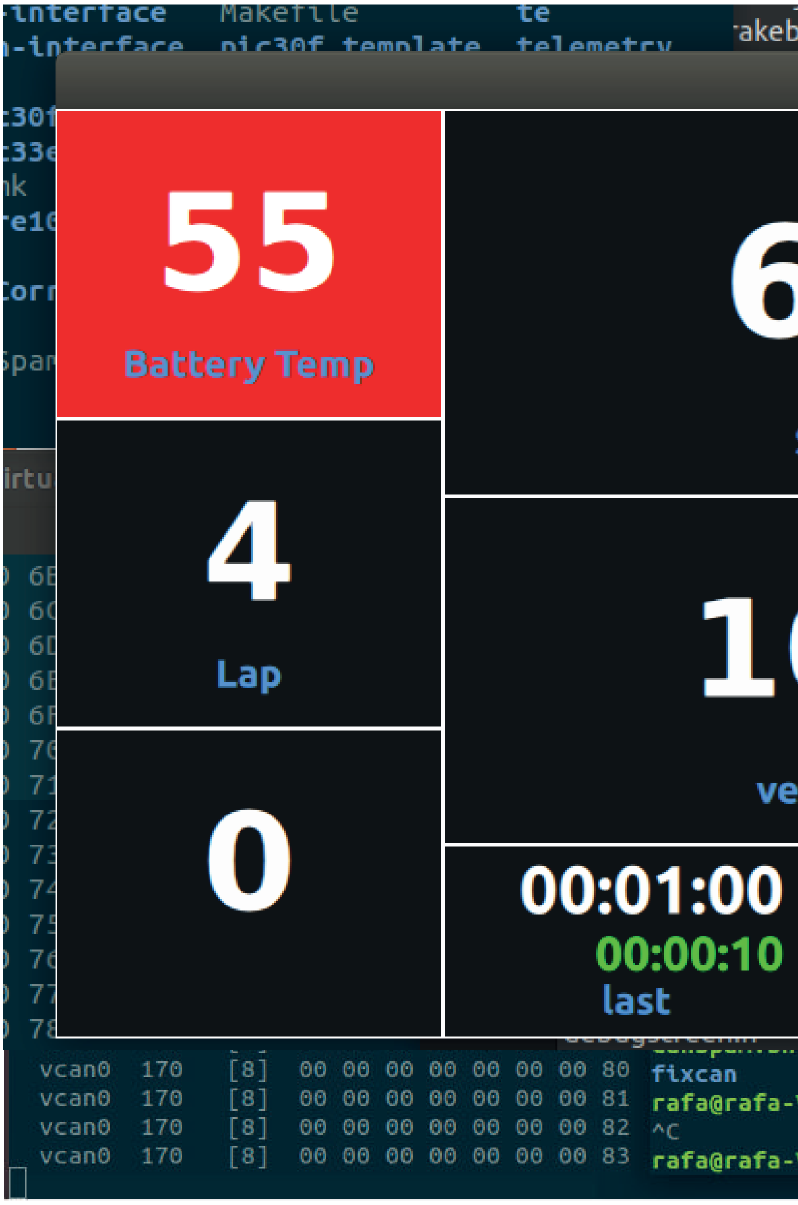
Miguel Lourenço



The Dashboard 101

Written by Miguel Crespo
Head of Software

Having built a reliable prototype in terms of hardware, it was time for the software to follow. Despite already having successfully implemented telemetrical methods for data collection, there was still a lot to do in order to maximize not only this new feature but also the interaction between driver and car.



It was exactly this interaction that motivated the significant changes made on the driver's interface.

The driver's interface is the software that allows the driver to view various information about the car.

Compared to last year, the main focus of the driver's interface design remains the same: present relevant information about the current state of the vehicle during the different dynamic events. The data that is presented to the driver is divided into two categories:

General vehicle/race information, such as the percentage of energy remaining in the accumulator and lap times. Parameters that the driver can alter during the course of an event, such as torque front/rear and brake bias.

The programming language used also changed from C to C++, due to the fact that having to run on a microcontroller, the consequent low-level implementation of the final product would make it little modelled and difficult to maintain.

This way, by swapping to C++ and using the Qt framework, the interface became more flexible not only in terms of graphic design but also in terms of maintainability and scalability.

Nevertheless, these new features demand more computational power, therefore this software will run on an onboard Raspberry Pi, which will allow improvements on the ability to communicate as reporting the status of different critical systems through colours in the dash. Another new feature of the driver interface is the existence of several screens through which the pilot can navigate so that the available information is the most appropriate possible to the type of dynamic event being carried out.

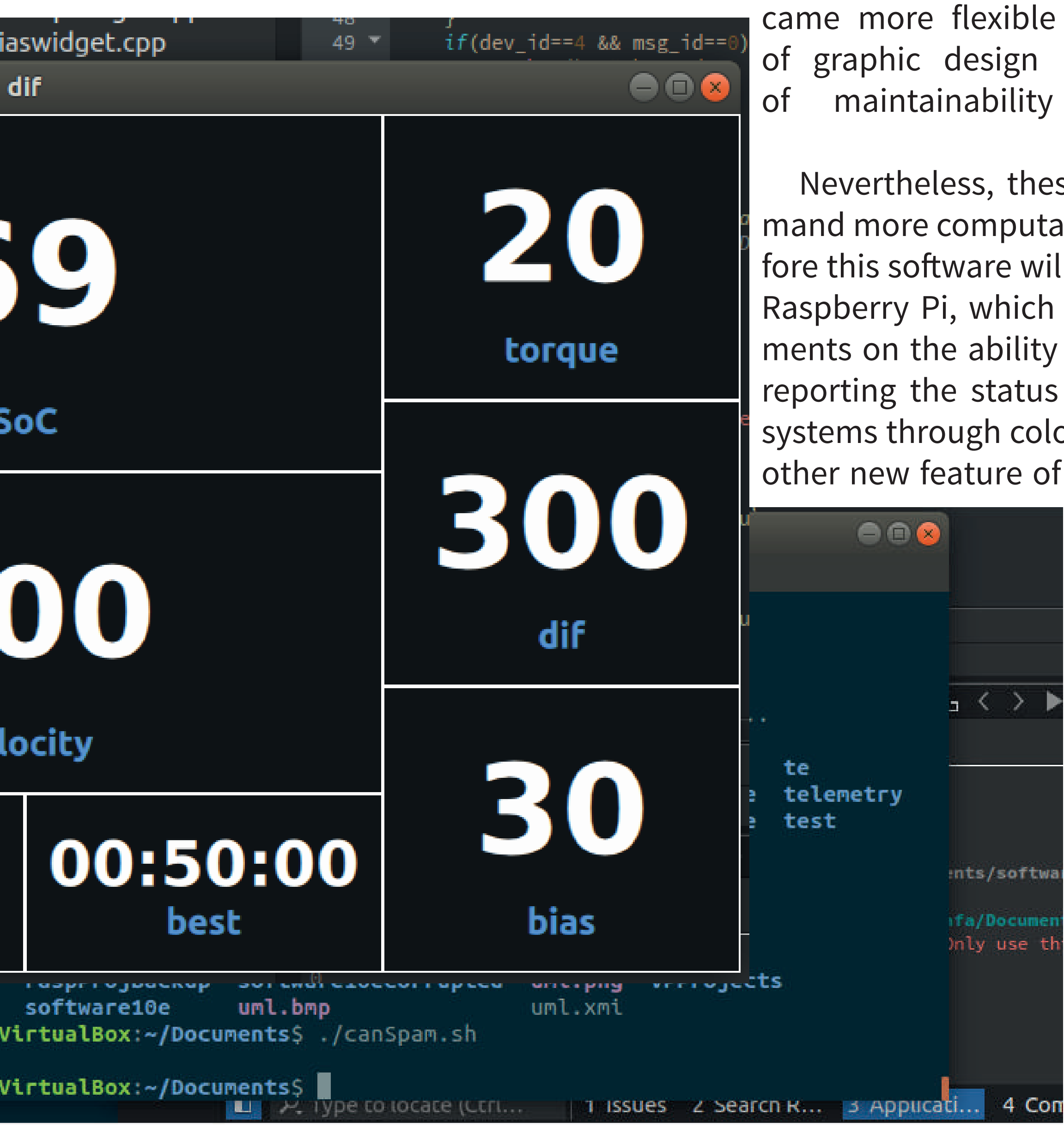


Fig19. Driver Interface with example values

R&D: *A two stage Drive Train*

Written by Tiago Carvalho
Drive Train Developer

This year, a second drivetrain was developed in order to be validated for future prototypes.

In this drivetrain the transmission that once was a one and a half stage becomes a fully second-stage transmission and it is pushed inside the wheel. To make this possible the Hub now takes the roles of: housing the transmission, the brake discs, while also connecting the drivetrain assembly to the rim by means of a specifically designed rim centre.

In this new drivetrain, the Upright no longer holds the previous function of housing the hub and the transmission. Making it possible to take upon the functions of the front plate and cooling jacket.

Even though efficiency will be lost in the gear meshing by increasing the number of stages, the overall performance of the drivetrain assembly will be increased. In addition, the system presents the following advantages:

- More suspension geometry freedom, since the motor no longer interferes with the suspension rods.
- Aerodynamically, there is less motor surface disturbing the air flowing between wheel and the chassis, reducing the drag and improving the overall airflow.
- The cooling jacket is now made of aluminium, increasing the heat transfer rate and improving its efficiency.
- The loads are more easily distributed, allowing for more lighter parts, namely the hub.

Fig20. Comparison between what will be the FST 10e (left) and FST 11e (right) Drive Train Assembly

Fig21. MJFv2 exploded view

The members of Powertrain started the year with a new goal: finishing the mechanical design of the 3rd version of the MJF motor, called MJFv2, initialized in the previous year.

The main objective is to be the first MJF to be integrated in a team's race car. To be able to achieve this goal, the MJFv2 was designed to be mechanically compatible with the AMK motor (the current commercial motors used), presenting the same external dimensions, the same type of connection to the transmission (same spline), and the same support points between motor and the upright endplate.

Allowing an easy assembly procedure was also a main concern, so all parts were designed in order to be independent, and easily replaceable by new ones if needed. For the shaft assembly to comply with this goal, it was decided that the torque transfer between the rotor and the shaft would be done using threaded shafts to unite the parts, and by assembling the shaft by slipping.

In parallel with the motor's design, the team intends to create a datasheet with the electromagnetic properties of the MJF. Thus, it was developed a testing document, in which all the performed tests were described.

Now that the mentioned objectives are almost concluded, a new challenge arises: creating an efficiency map for the MJF. This will allow estimating the losses as a function of torque and speed and the efficiency in each operating point of the motor.

For the time being, all these values can only be achieved at a theoretical level, because the motors are still being manufactured. The next step will be testing the MJFv2 in the laboratory to obtain realistic results for the efficiency map and create its accurate datasheet.

R&D: *One step closer to MJF*

Written by Paula Cunha
eMotor Developer

ELEC

RLESS


TRIC
DRIVE

1. What exactly is an autonomous/ driverless car?

An autonomous car is such that the driving tasks are not performed by a driver but instead by a set of sensors and computing units. These tasks include perceiving the environment, planning and decision-making, and controlling the vehicle to take it from point A to point B. In particular, FST10d's Operational Design Domain or *ODD* is such that the vehicle is capable of travelling within the tracks found in Formula Student Dynamic Events.

João Pinho, Project Manager for FST 10d

2. How can a driverless car distinguish what's track from what's off track?

The car can perceive its environment through camera image analysis and by processing the LiDAR point cloud. With the combination of those two systems we can estimate the cones positions and therefore the centerline of the track. The identification of the color of the cones is key to identify the track boundaries and therefore map in memory correctly what is track and what is not.

Pedro Coelho, Software Developer

3. Can messages be sent to my prototype during competitions from a far ?

No, the only device that can send commands by wireless communication is the RES which is a must-have on every DV prototype. It basically triggers the DV Shutdown Circuit when the remote emergency stop button is pressed, and performs race-control-to-vehicle actions such as sending a "Go" signal (that replaces green flags).

João Tomé, LV Electronics Developer

4. How does the car perform actions as stop or steer?

Well, when you take the driver out of the car, you need specially designed systems to accomplish such tasks.

The EBS is the central brake system for the autonomous vehicle, providing almost instant brake power, which can be used to immobilize the car or decelerate it to enter the turns at just the right speed.

The STA is the autonomous steering system which is powered by a servomotor directly attached to the steering column of the vehicle, it can go from lock-to-lock in just a split second.

João Rego, Mechanical Integration Developer

5. During competitions, is the track known beforehand?

Yes and no, for the disciplines of Autocross and Trackdrive the track is unknown, while for the disciplines of Acceleration and Skidpad the track has fixed dimensions. This allows to construct a map beforehand and use localization algorithms so that the car can localize itself within the track boundaries. When the track is unknown we rely on perception to keep the car within the track limits. Using the detections from both LiDAR and Camera, which is validated through our sensorfusion pipeline, we construct a binary tree of possible paths with an associated cost using Delaunay Triangulation. At the same time, we run an algorithm of SLAM in order to construct a map and localize ourselves in it for the remaining laps.

Luís Lopes, Software Developer

6. Are driverless cars a good idea?

Absolutely. Keep reading to find out why!

Scrumming Made Perfect

- An Example of an Agile managed project

written by Maria Carolina Barata & João Pinho

As a novel project for FST Lisboa, the FST 09e adaptation into a DV class competitor required a careful deliberation as to define what would be the right project management methods to apply.

Since there was no prior experience that could serve as a starting point for discussion, the team scoped out already existent DV teams by going to their competition pits and questioning about what had worked for them in the past and what were the mistakes they wished they hadn't made. With that in mind, and the likes of alumni with experience in planning and management, the team started to sketch the first project guidelines.

Given the heavy load of software-related work, it was desirable to resort to a framework that could allow having smaller, more objective tasks which progression and conclusion would be more easily tracked, said project Manager for Driverless João Pinho.

Thus, the development approach that suited best was a strongly exploratory and feedback driven one that would allow a constant adjustment of the scope based on the analysis of the team's progress.

It was then that a specific project management framework popped out: *Scrum*

The team members engaged in this new project would also need to work with a learn-as-they-go, self organizing mindset, since feedback drives strategies as Scrum often overlap stages that are traditionally seen as sequential like building and testing.

By having members working in small teams, in the same product, rather than individually on their own modules, enhances cooperation during the development process and reduces the potentially negative effect of specialists, which may hinder other team members' ability to help in critical periods of the project, like during testing period, said Pinho.

So, in order to increase the odds of successfully developing an autonomous prototype, the team began its *Agile crusade*.

But how does a Scrum managed project work on a daily?

And how does it differ from other project management strategies?

Keeping in mind that every project is different, in the team's specific case the Scrum implementationtontation follows the basic concepts:

THE PRODUCT BACKLOG

This is a dynamic list of all the work that needs to be done/ might be needed for the product with established priorities for each task. These tasks contemplate implementation of new features, bug fixes, theoretical research or documentation, as well as initially unexpected tasks, such as fixes, or extra features. But before starting any work, the team gathered in a meeting to divide the big project into bite-size pieces.

A bit like subproducts within the big product.

– LiDAR[1] - processing pointcloud to detect cones, and their distance to the car.
– Vision - processing images to detect cones, their colour, and their distance to the car.
– Control - trajectory and actuators reference generation, given the information received of the track and the vehicle model.
– SLAM[1]- obtain a closed-loop map of the previously unknown track layout.
– Estimators - fuse sensor data to estimate car state variables, e.g. position, velocity and orientation.
– Simulation & Code Testing - prepare the simulator for algorithm tests and setup the framework for unit tests and automatic simulation tests.

THE SPRINT

Everyday, in person or virtually, the team will inspect and adapt the progress towards the sprint goal based on each members' feedback.

SPRINT REVIEW & RETROSPECTIVE

At the end of each sprint, the team has a meeting to review the work completed and the planned work that was not. The first half of the meeting is purely expository and includes only work actually finished. In the second half, the team will reflect on what went well and what didn't, as will identify what might be done to continuously improve. The achieved conclusions should have a direct impact on the next sprint, namely on the task selection process.

Sometimes, due to needed rework or delays in delivering, and overdued deadlines, the team may have to resort to an easier solution for subsequent tasks rather than a more complex one that might have resulted in a better performance.

Technical Debt is a concept everyone involved in Scrum should be aware of, which will inevitably take place through the project and should always be present in the back of the project manager's (product owner) mind when defining a sprint backlog and assigning priority levels to each and every task.

Finally, and despite being just over halfway through the FST 10d project, investing on Agile frameworks and bending those concepts to the team's needs have undoubtedly added value to the way the team works as it will surely mark its future functioning.

The Sponsor Check: Novabase

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With 30 years of history, Novabase is the Portuguese leader in Information Technologies. It operates in the Telecommunications and Financial Services market and also has a business dedicated to IT recruitment (Neotalent) and a venture capital area.

It has offices in Spain, United Kingdom, the Netherlands, the United Arab Emirates, Angola, and Portugal. It has the talent and dedication of more than 1,800 employees from 17 different nationalities

Novabase Academy

Created in 2006, Novabase Academy is the company's program dedicated to the selection and development of talent leaving Universities. Since it was created in 2006, the program has already recruited around 1500 new employees.

It is through this program that candidates are selected to integrate the different business areas at Novabase. The most sought after profiles are Computer Science Engineering, Electrical and Computer Engineering, Telecommunications and Informatics Engineering, Business Management Informatics, Biomedical Engineering, Mathematics and Management, among others, with Instituto Superior Técnico dominating hiring in 2019.

The Novabase Academy recruitment and selection process takes place throughout the year.

So, for those who want to join team Novabase, send your application to academy@novabase.pt.

[1]*Novabase Headquarters in Lisbon as featuring image of this article.*


NOVABASE

Per cep tion *[uncountable] (formal or technical) the way you notice things, especially with the senses*

When talking about a car with no driver, the word perception has a new meaning.

The first form of control regular cars have is the driver's own perception of the things that surround him. When you're driving you can distinguish what's road from what's sidewalk as you can see the lefts and rights you'll have to take, meters before you actually turn the steering wheel.

What happens when no one is driving the car?

With one of its first applications during the *Apollo 15 mission*, LiDAR is a surveying method that measures distance to a target by illuminating it with laser light and, with a known velocity, measuring the time that the laser takes to reach the radar. This method, put into practice by astronauts to map the moon's surface back in 1971, is the starting point for the FST10d software pipeline.

After measuring the distance to a certain target the sensor on the LiDAR delivers every surface within 120m of the car as a set of data points - *the pointcloud*.

Pointclouds have, typically, several thousand points (e.g. VLP-16 uses 300 000 points/sec with a refresh rate of at least 10Hz) which means that processing all of the points is very time consuming. If the processing time exceeds the refresh time, the LiDAR will start missing pointcloud messages.

To avoid so, processing must be improved somehow - one way to do that is by using *filters*. In order to reduce the number of processed points, filters remove unwanted points, such as points that are out of the intended ROI[1], or even reduce the number of points uniformly.

As said before *(see FAQ's)*, in the Formula Student context, an autonomous prototype must be able to follow the track that is demarcated by blue cones on the left and yellow cones on the right.

A great way to simplify the track's identification is by removing the ground points - *ground removal* - to better cluster objects (in this case cones). Since the ground plane is a big flat surface, identifying it is a fairly easy task that will speed up the pipeline by removing several points from the pointcloud.

Based on that and on the fact that a lot of pointcloud points during the racing events are ground, using this algorithms proves to be rather effective.

Wait a minute, what does it mean? To cluster objects?

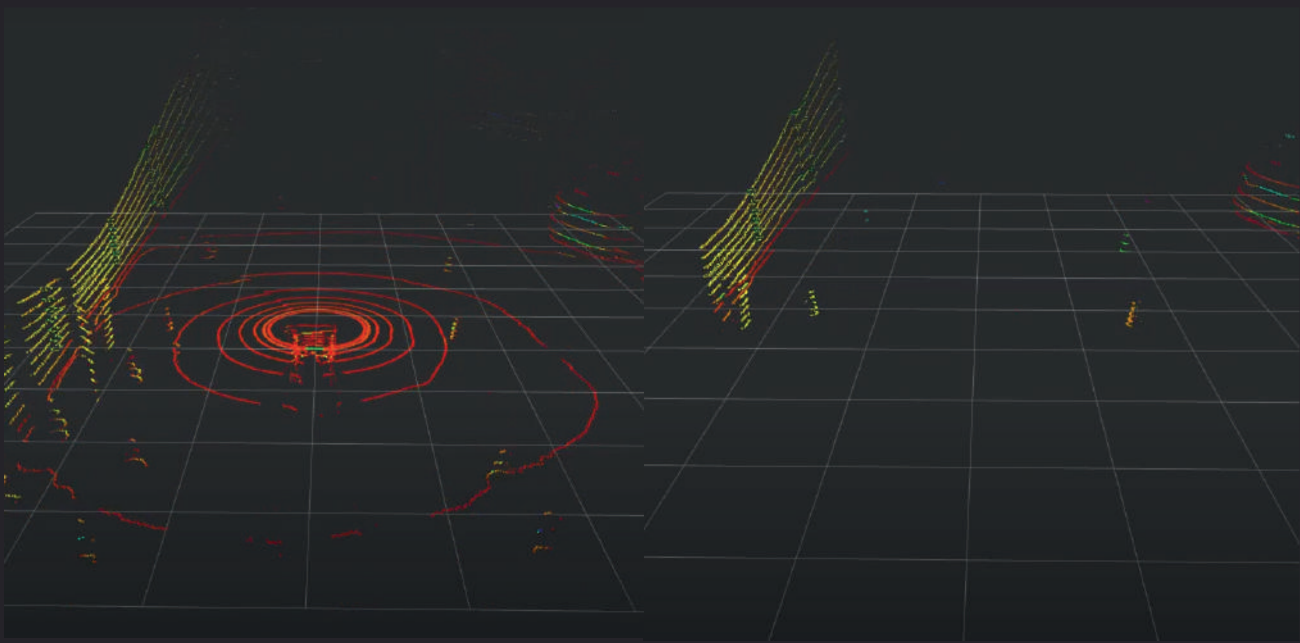


Fig22. LiDAR perception images with cones identified has different clusters.

Clustering is the task of grouping a set of points in such a way that points in the same group *(called a cluster)* are more similar, in some sense, to each other than to those in other *clusters*. It is a main task of exploratory data mining, and a common technique for statistical data analysis, used in many fields, including machine learning, pattern recognition, image analysis, information retrieval, bioinformatics, data compression, and computer graphics.

Cluster analysis itself is not one specific algorithm, but the general task to be solved. It can be achieved by various algorithms that differ significantly in their understanding of what constitutes a cluster and how to efficiently find them.

In the team's case clustering is based on the relative distance between points.

But let's go back a little…

Having removed the ground plane using the RANSAC method, the remaining points will then be clustered to locate the different unidentified objects. This clustered objects will then be used for identification.

Again, in a Formula Student perspective, the clustered objects used to identify the track are the yellow and blue cones and, given their main role on the right track mapping, it is necessary to find methods that allow to validate as cones all the detected and previously reconstructed clusters.

In the previous images we could clearly identify that each cone is detected as a cluster because all the points have the same color. The fact that each cone has a different color proves that they are detected as different clusters.

Apart from the LiDAR, the FST 10d perception system also includes a camera for cone detection using image data and a neural network to divide the image into regions and predict bounding boxes and probabilities for each region. The network has been trained with a custom dataset of over 40000 images containing driverless formula student cones. This dataset - FSOCO is a collaboration between FS teams and aims to accelerate the development of camera-based solutions into assisting in the process of planning the track where cars must perform.

The Sensor Fusion Pipeline is also an important part of the car's perception methods, since it handles redundancy in LiDAR and camera cone detections and lessen their drawback effect.

How does it work?

It consists in projecting each LiDAR cone candidate represented by its cluster centroid in the 2D image plane, and evaluating whether it lays inside the camera's bounding box. The output is the cone's position using LiDAR's 3D position and the camera's colour.

So now that the FST 10d is able to perceive, how can it stay on the right track at all times ?

Written by David Ribeiro & Pedro Coelho
Software Developers

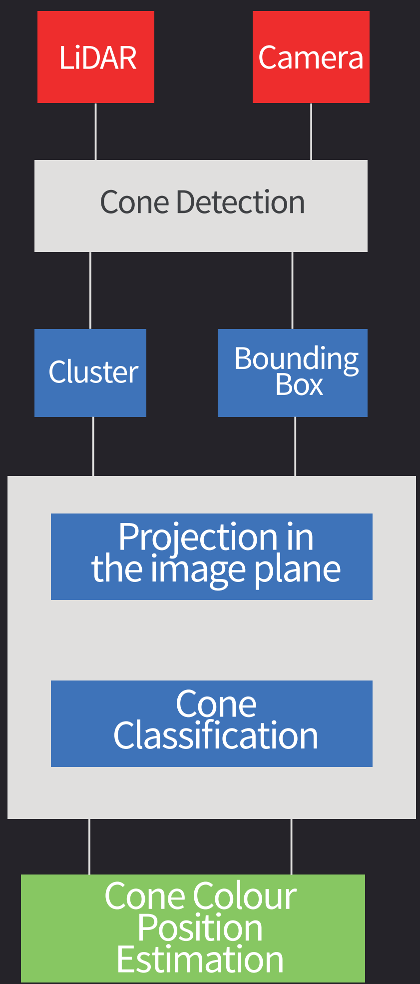


Fig23. Sensor Fusion Pipeline

Es ti ma tion *[countable] (formal or technical) a judgment about the levels or quantity of something*

As any moving robot, autonomous cars have an associated error regarding their estimated position. This error could potentially translate in a wrong trajectory and ultimately provoke undesirable consequences like going off track.

To avoid so, the vehicle state with respect to the track is provided by the estimation module. By means of filters and a SLAM algorithm, it is possible to predict the next set of states that the car is going to take solemnly based upon the data the vehicle receives *(see perception)*

EXTENDED KALMAN FILTER (EKF)

Used to estimate the vehicle's velocity as well as the yaw rate. The EKF allows the predicament of the next set of states that the car is going to take as it is the Kalman Filter adaptation for nonlinear systems. This filter linearizes the system by using a Taylor expansion. The motion model used assumes constant acceleration and turning rate.

SIMULTANEOUS LOCALIZATION AND MAPPING (SLAM)

SLAM addresses the problem of building a map of a certain environment from a sequence of landmark measurements obtained from a moving robot. Due to the previously mentioned error on the car's state, the mapping problem also imposes a localization problem, hence the necessity of simultaneously localize and map. Accordingly, the implemented algorithm (FastSLAM) decomposes the problem into a localization problem and a collection of independent landmark estimation problems that are conditioned to the robot's pose.

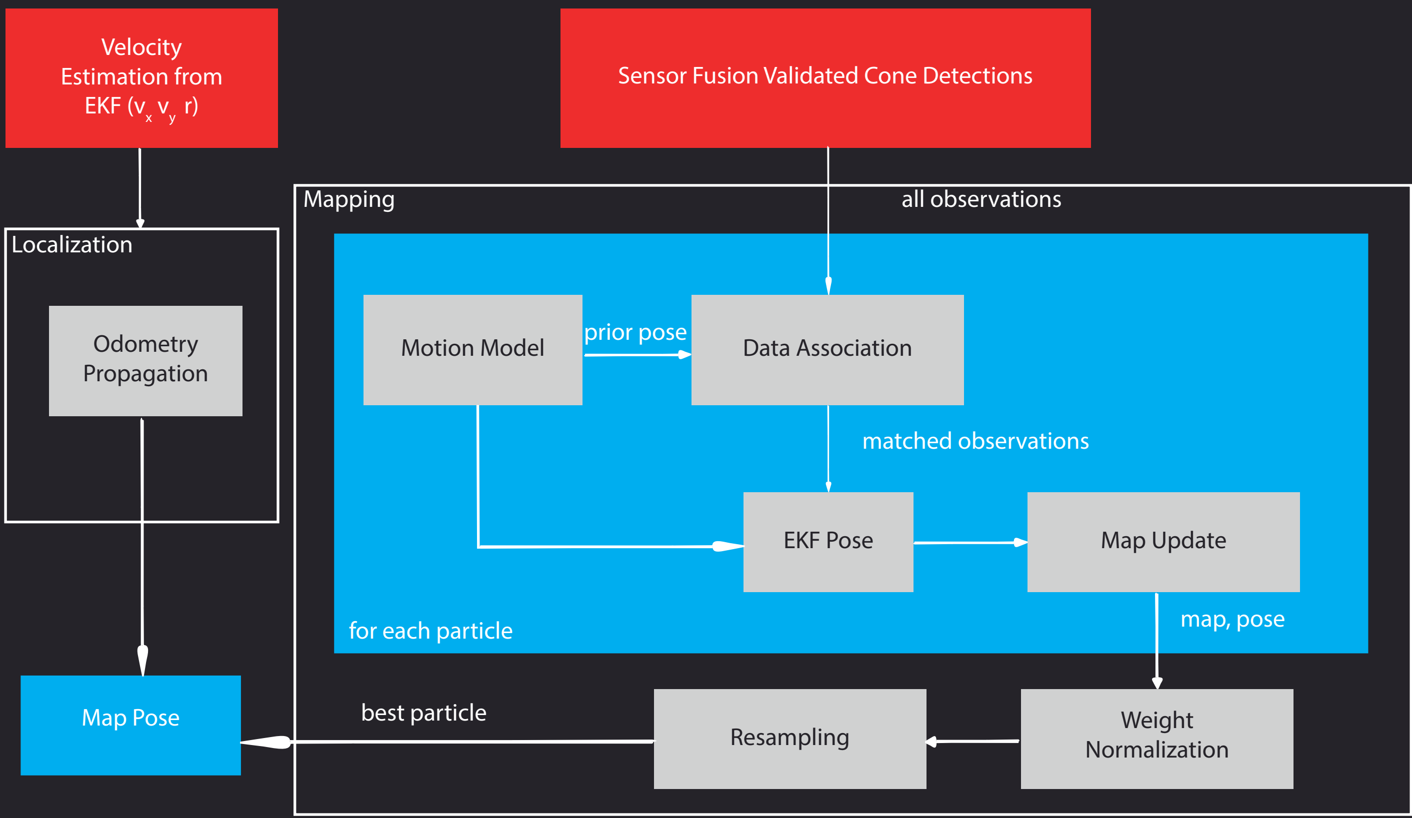


Fig24. SLAM Flowchart

Written by Diogo Morgado & Francisco Quelincho
Software Developers

Con trol & Tra jec to ry

determine the behaviour or supervise the path followed by an object moving under the action of given forces

It is known that the track is often new to a DV prototype during the first lap, thus the car needs to compute a trajectory to keep him in between the track limits based on the observations made by the perception pipeline.

For that reason, and in order to complete the first lap, it was mandatory to develop an algorithm capable of generating a trajectory following the center line between cones from each side of the track.

In order to accomplish this, several approaches were considered, but the one that proved to be the most reliable one was to construct a binary tree of possible paths resorting to Delaunay triangulation, using the detected cones as vertices.

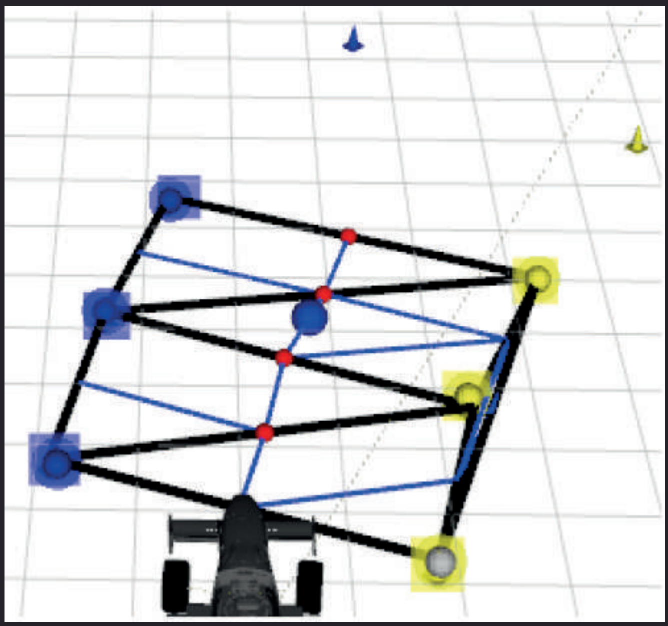


Fig25. Binary tree construction

With Delaunay computed, the root of the tree is defined as the middlepoint of the closest edge.

With the first waypoint computed, there are two possible next waypoints, that correspond to which of the remaining edges of that particular triangulation. By repeating this process for the remaining triangulations, a binary tree of possible paths with an associated cost is constructed. The cost function takes into account two middlepoints, and weights them independently. Both the distance and angle variation are normalized based on an expected value. Also, this function penalizes paths that pass between cones of the same colour.

Now, with the tree completed, finding the best trajectory becomes a matter of finding the path with the lowest cost.

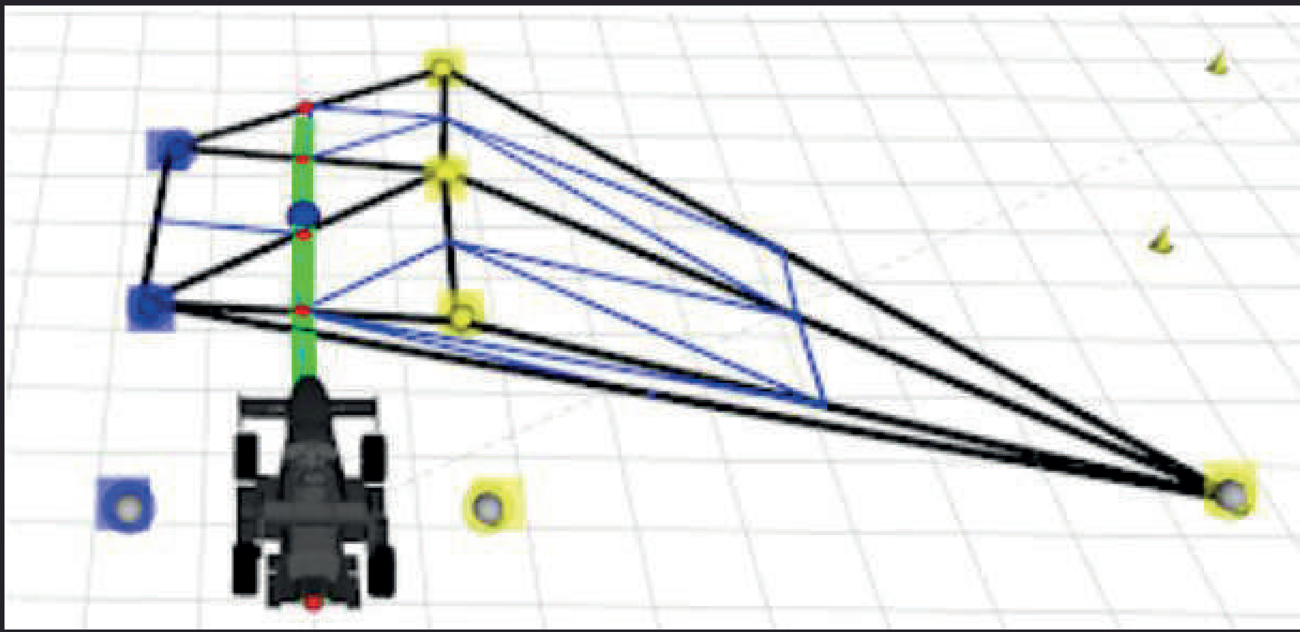


Fig26. Right trajectory with binary tree and cost function that penalizes paths between cones of the same colour

To improve this path planning algorithm's calculated trajectory, is important to implement control actions that allow an error minimization and a reduction on the system's oscillations.

LATERAL CONTROL

The lateral controller used is a simple pure pursuit controller that computes the desired steering angle command δ as follows:

$$\delta = K_\delta \frac{2y}{l}$$

Where K_δ is the controller gain (enables adjustment of its response and transforms the curvature angle to the corresponding steering actuator angle), y is the distance along the lateral direction measured from the vehicle to the goal point, and l is the distance to the goal point.

Both y and l are adjustable by changing the lookahead distance, tuned for each dynamic event.

LONGITUDINAL CONTROL

So, implementing a PI controller aimed to exploit available information as to judge whether or not the car can go faster, or even need to start braking.

This controller receives a desired velocity from the global trajectory, but on the first lap mode (when the track is still unknown), the desired velocity is a function of y. The controller outputs a velocity setpoint which is fed to the motor's controller.

MISSION TRACKER NODE

Lastly, provided the car is able to stay within track limits, it is necessary to enable the vehicle to know when and where to stop. A few conditions are checked:

Perception: detect orange cones to recognize stop area or start line for counting laps.
Estimation: generate a location that corresponds and compare the vehicle's estimated location with this point.

A number of timers and nuances are implemented to ensure robustness and therefore prevent poor decisions, e.g. duplicate lap counts and stop before the finish line.

Written by Luís Lopes & Miguel Santiago
Software Developers

Steering With No Hands

Written by João Rego, Mechanical Integration Developer

Now that we've explained the software developed to, hopefully, overcome the ultimate autonomous challenge: *a car without a driver needs to steer without a driver, it is necessary to do* so physically. For that, an autonomous steering actuation mechanism must be designed. This system is called the Steering Actuator (STA).

A STA is mandatory for a driverless car, as it ensures performance and also, safety. Besides DV rules, it also needs to be compliant with the rules regarding the implemented manual steering solution.

Thus, given that the FST 10d is an adaptation of a previous EV class prototype, the mechanical part of the STA is also an adaptation of the previous steering system, with actuators replacing the movements that a driver would perform to turn right and left.

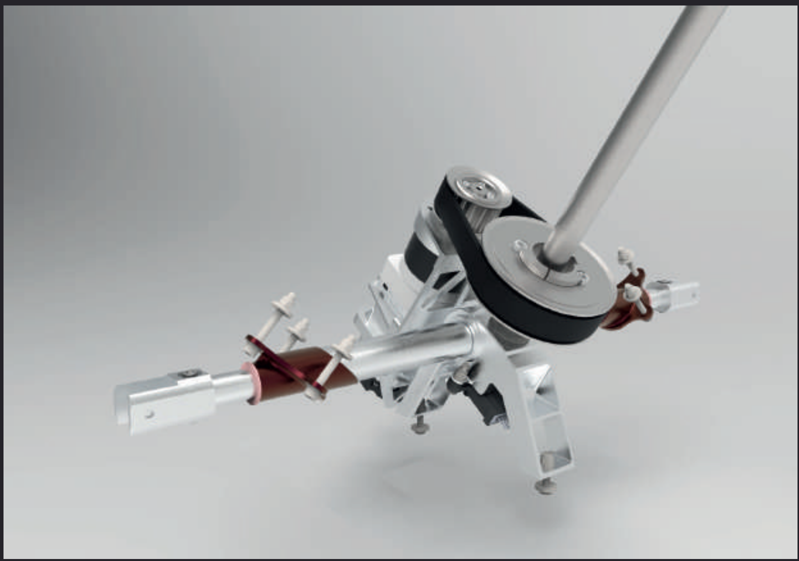


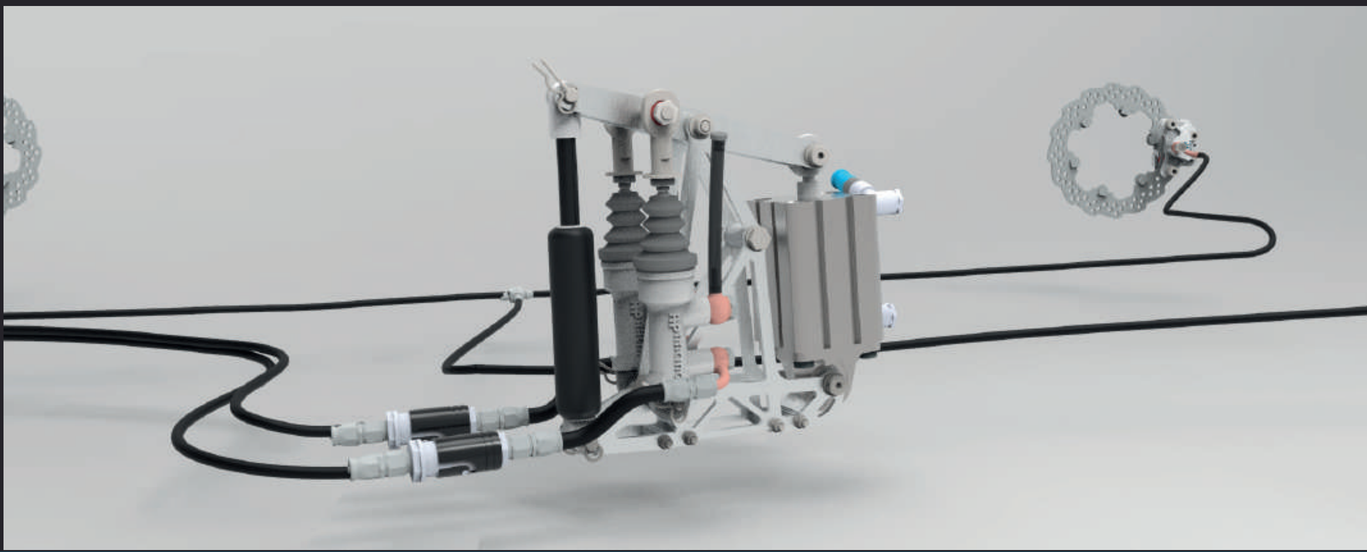
Fig27 & 28. STA Assembly

As showed, the STA system consists of a 24V DC Motor actuating the steering column by a pulley and timing belt mechanism. The actuator is attached to a support which is fixed to the steering rack housing.

The DC Motor nominal torque is 1.0 Nm while the peak torque reaches 2.5 Nm. Nominal speed is 3000 rpm. With 10:1 ratio gearbox and pulleys' different diameters, the systems yields a steering torque of 16 Nm with a side-to-side time of just 0.5s, in nominal conditions.

There are different sets of pulleys so that the overall gear ratio can be adjusted: the trade-off between steering torque and speed can be adapted as required.

Fig29. EBS Assembly



Braking with No Foot

Written by João Rego

The mechanical part of the EBS is an adaptation of the previous braking system, with actuators replacing the movements that a driver would perform to hard brake (in case of an emergency) or to maneuver the car around the track, maximizing performance.

The design system is composed of three main subsystems:

HYDRAULIC SYSTEM

Builds up pressure to actuate on the base vehicle's brake calipers. It has two extra master cylinders that are actuated in the *Trebuchet* . There is a parallel line to that of the pedal box, both end at a shuttle valve whose function is to allow the flow with the g reater pressure to pass. The output of this valve is the already existing brake line.

MECHANICAL SYSTEM

Converts forces between the different systems. It consists of two main elements. The cage which holds the components together, and the lever that allows for force transducing. The lever is adjustable to allow different ratios between the forces applied.

PNEUMATIC SYSTEM

Controlled by means of a solenoid valve to achieve the desired braking mode,i.e.the necessary pressure on the pneumatic cylinder. It also includes a manual valve that when actuated releases the brakes so that the vehicle may be pushed.

Electric Architecture

LV SYSTEM POWER SUPPLY

Due to increased LV power demands, mainly rising from the STA, a LV Battery was developed since the existing DC/DC in the FST 09e accumulator could not handle this power demand.

COMMUNICATION

The existing CAN Bus line was adapted in some cases to connect new devices. Furthermore, there is now an Ethernet and USB cable to communicate with the LiDAR and camera, respectively.

ESSENTIAL CONTROL ELECTRONICS

Besides the rules-required PCBs, e.g. Non-Programmable EBS[1] and ASSIs[1], a new PCB - EBS Supervisor - has also been designed. Its main goal is to not only distribute power to the new devices and handle new IO ports, but specially to handle the EBS startup procedure and continuously monitor its data, to ensure its functionality at any point.

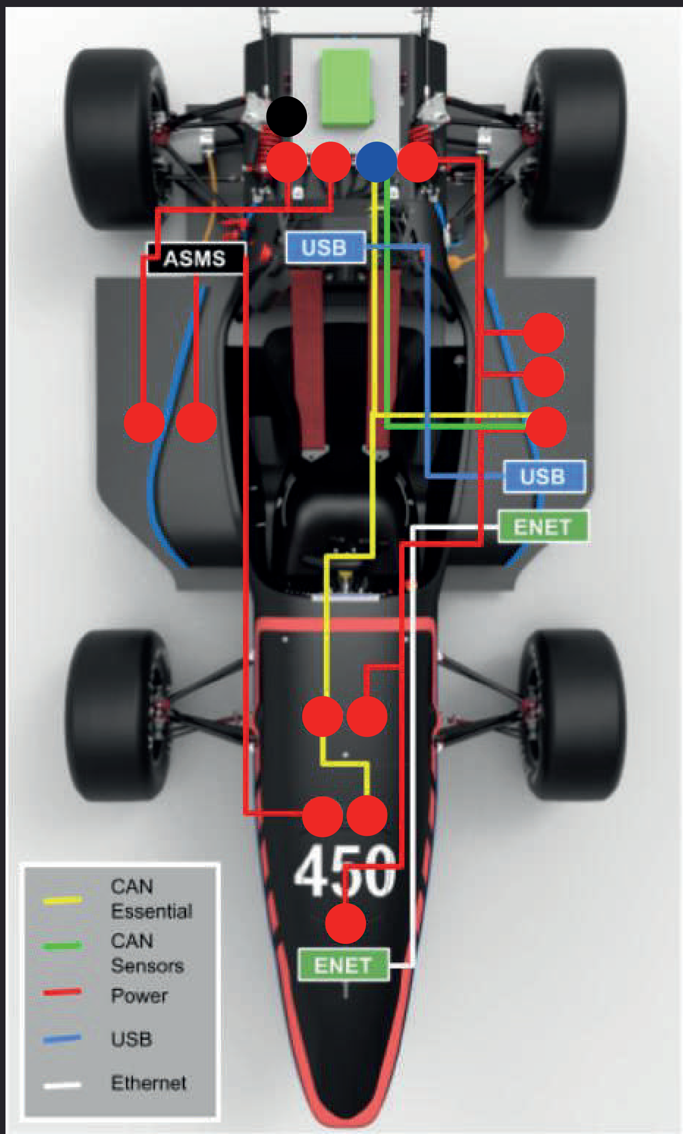


Fig30. FST 10d Harnessing Diagram

Written by João Tomé
Electronics Developer

Glossary

ASSI — Autonomous System Status Indicator
Indicates AS Off, AS Ready, AS Driving, and AS Emergency with different illumination according to Regulation

CAN — Controller Area Network
CAN Bus, the nervous system, enabling communication between all parts of the body.

CGAL — Computational Geometry Algorithms
Branch of computer science devoted to the study of algorithms which can be stated in terms of geometry.

DV — Driverless
Alternative to autonomous, it is the prefered term when it comes to Formula Student.

EBS — Emergency Brake System
See FAQs for general meaning and Braking With no Feet for detailed explanation.

EKF — Extended Kalman Filter
Considered the standard in the theory of nonlinear state estimation, navigation systems and GPS.

LiDAR — Light Detection and Ranging
Method for measuring distances by illuminating the target with laser light and measuring the reflection with a sensor.

LV — Low Voltage
Defined as 50V or less.

ODD — Operational Design Domain
Description of the specific operating domain(s) in which an automated function or system is designed to properly operate.

RANSAC — Random Sample Consensus Algorithm
Iterative method to estimate parameters of a mathematical model from a set of observed data.

SLAM — Simultaneous Localization and Mapping
Computational problem of constructing or updating a map of an unknown environment while simultaneously keeping track of an agent's location within it.

STA — Steering Actuator
See FAQs for general meaning and Steering With No Hands for detailed explanation.

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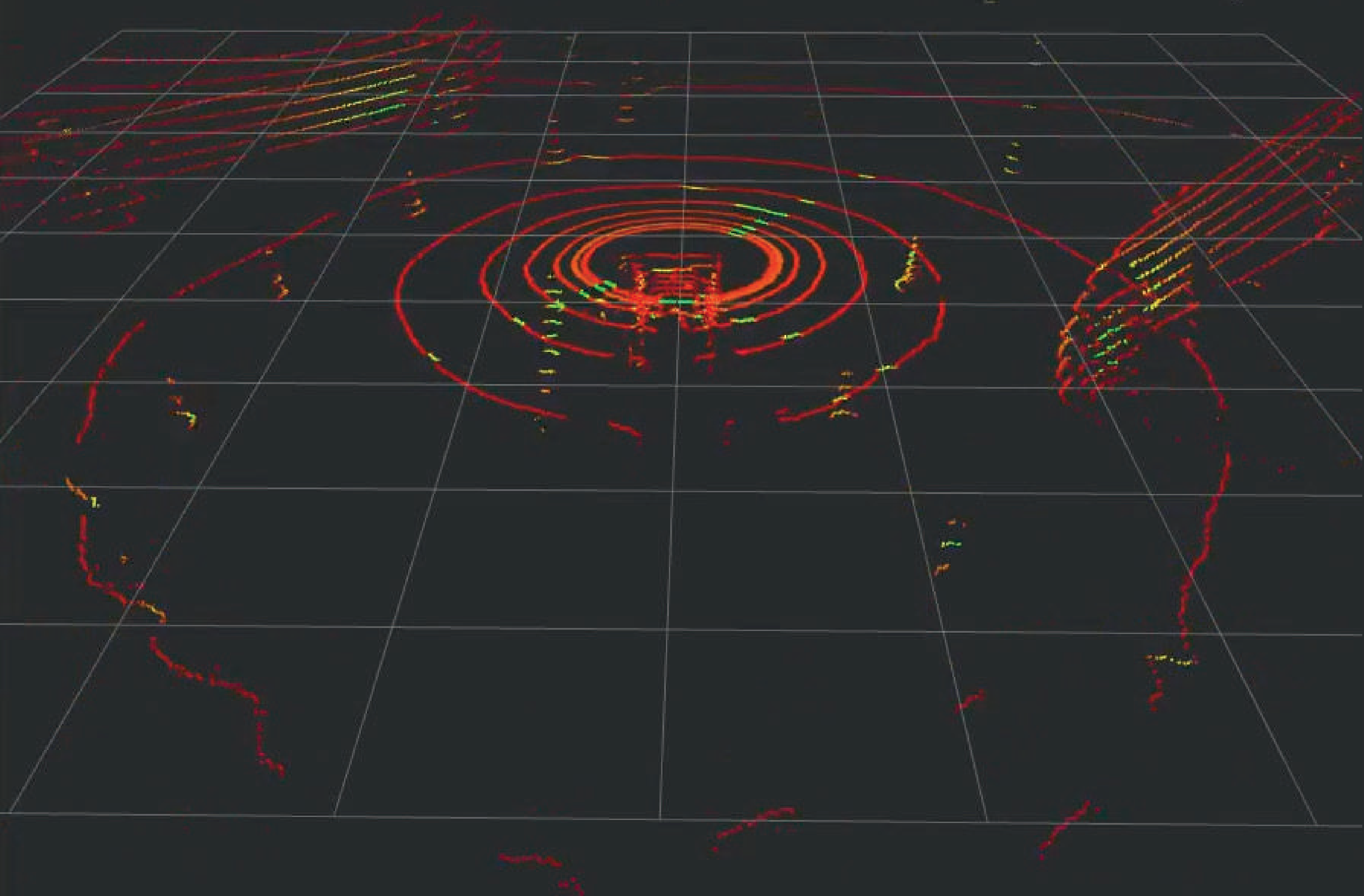

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