Project Initialisation Report

NXP Cup 2020 EMEA Car - 4th Year Group Project

Project Definition [AH[1]]

Introduction

The EMEA NXP Cup is an annual global competition held amongst European, Middle Eastern and African (EMEA) teams of students attending either school or university. The teams must design and build an autonomous model car capable of driving itself around a track while aiming to do so in the minimum possible time. Additional challenges such as obstacle avoidance and speed limit awareness can be undertaken to score additional points to win the overall competition.

Aims

As a fourth-year group project, a three-student group will design and build an autonomous model car to take part in the EMEA NXP Cup in May 2020. The car will not be continuing a previous design or construction. The specifications and constraints of the car are bound by the competition rules and a £600 budget. The project aims to construct a car to navigate the track in the shortest time and complete all supplementary challenges to win the cup. Tasks can be roughly broken down into computer vision, steering control and speed control for distribution of work within the team.

Key Competition Rules

- The route will be defined by two 20 mm width black lines either side of a matte white track with a total width of 550 mm
- The car must maintain at least two wheels within the track at all times
- The car must be fully autonomous once configured for the race, this includes stopping in the track within 2 m of the finish line and forbids any wireless communications
- A camera must be the primary navigation sensor
- The car must be powered by two or fewer electric motors and can have a maximum of four wheels
- All microcontrollers other than those in a commercial electronic speed controller (ESC) must be NXP branded, as must any sensors which are offered by NXP
- Lithium-Polymer cells are limited to 2s (7.4 V)

Objectives

Primary

- Implement a computer-vision based sensing system for detecting track direction, curvature and the start/finish line, ultimately generating a 2D map with vehicle attitude referenced against it.
- Implement closed loop steering control to follow the desired track.
- Implement closed loop speed control so that speed can be varied in response to the curvature of the track.
- Purchase a chassis optimised for on-road performance which will also be capable of accommodating the above requirements.
- Purchase motors and speed controllers which have the ability to maximise the capabilities of the above chassis.

Secondary

- As well as detecting the start/finish line, the computer vision system must be capable of locating objects on the track and detecting speed restriction markers.

[1] Introductory Technical Discussion has been done individually

- The system should be capable of calculating a ‘racing-line’ track to ensure maximum speed can be carried through corners.
- Modify steering control to be capable of accommodating varying vehicle speeds.
- Implement a form of torque vectoring to enable higher vehicle speeds through corners while maintaining stability.

Introductory Technical Discussion

Computer Vision [HS]

(a) Original (b) Canny (c) Hough

Figure 1: A comparison of image processing transforms: (a) The University of Sheffield coat of arms with outer border. (b) Canny edge detection of them original image. [1] (c) Hough transform of the canny edge detected image, detected lines are drawn on in red.[3]

Computer vision is the basis of how our car should drive itself based on the rules defined in the NXP Cup. Computer vision is the process of using optical sensors, usually cameras, to take in image and video information like a human does, in this case we are trying to extract information about the track. Computer vision can be used to give much more information than just where the edge of the tracks are, allowing for much more complex algorithms to increase the car performance/accuracy. Some possible methods include: Track line detection, neural network driving, motion analysis and map tracking

The simplest computer vision method would be the use of transforms and masks to detect the edges of the race track. Given the harsh cutoff between black and white track defined in the NXP track specification, an edge detection algorithm would be useful, such as a Canny edge detector, to reduce the points of interest in the image [1]. This essentially differentiates our image which highlights any edges (such as the side of the track), this differentiated image then has a threshold applied to only show the most important parts, this removes any noise or ambiguous edges. An example of this is shown in Figure:1(b). This line map can then be split into regions to determine if the track lines are too far left, right or tell if there is an upcoming corner. Straight lines found by the Canny detector can be picked up by an algorithm such as a Hough transform, this allows the lines to be represented by an equation for ease of analysis [2]. An example of these detected lines are shown in Figure:1(c). The Hough transform is, however, limited to straight lines could will suffer with chicanes or corners.

A popular solution to computer vision is the use of neural networks, most commonly the convolutional neural network (CNN) [3] which involves convolving down images into manageable amounts of data for real-time processing. CNNs could be used to detect straights, corners, chicanes and interchanges telling the program what the ahead track consists of. As with all assisted neural networks (NNs) the CNN would require training data to teach the algorithm what it's looking for which may require hundreds to thousands of data points to become effective.

Computer vision can also be used to calculate motion by analysing the image difference between frames. Optical Flow Algorithms calculate this disparity for each pixel leading to a vector map at each pixel in the image which can be used to tell speed and direction of objects in a scene [3]. This method would allow for a speed reading of the car including any slip, this known speed can also be used with the vector map to calculate distance by comparing the inverted magnitude of these vectors. Visual odometry however is based on a static environment and a moving camera which can be used to plot, in 2D or 3D space, the displacement of the camera between two frames leading to a sampled route [4]. The basis of these algorithms is: Feature Detection, Feature Matching and feature difference. There may however be issues using motion analysis algorithms with a plain track as there are few features that can be detected and matched between frames on long straights.

For this race the more information we have of the track the better, one way of doing this could be using and image stitching algorithm which would give an eagle eyed view of the track after one run [5]. This information could then be processed to create an optimal traversal line along with the corresponding speed, this type of system would require a method of comparing to actual position and speed, possibly as defined above. More track information could also be found by using a 2D diffraction grating with a laser which would create a matrix of laser dots, these dots fall in a very predicable fashion and using trigonometry the distance for each dot can be calculated. This allows the computer vision software to know exactly how far away the edges of the track are giving more data to use.

Overall computer vision can be used for many different aspects of the self driving car but selection of methodologies will likely be an iterative, agile methodology constantly adding and removing algorithmic features to find the best combination.

Steering Control [DC]

Methods of steering control tend to fall within three types of control – a geometric controller, a controller based on a model or a feedback controller [6].

Geometric Controllers

Geometric controllers generate curved paths to follow to the desired location and utilise the geometric relationship between the generated path and vehicle to calculate the steering angle required – this type of method is popular for autonomous cars for its simple implementation, fast calculation speed and lack of need of a kinematic model. The first geometric controller method, Pure Pursuit [7], was developed in 1985 and used to have a car maintain the centre of a road. Pure Pursuit operates by taking look ahead distance l_d and generating a curve which connect the rear wheel to a goal point l_d away, and setting the steering angle to allow the car to follow this arc. By following this arc, the car can always maintain a smooth path to the goal point, and by changing the goal at each instant to always be at a distance in front of the car, a loop of smoothly pathing and ‘chasing’ the goal point can be created. The required steering angle φ is calculated as:

$$\varphi(t) = tan^{-1}(\frac{2L \cdot \sin\left(\alpha(t)\right)}{l_d})$$

Where α is the angle from the rear wheel to the goal point, L is the length of the car and l_d is look ahead distance.

Pure Pursuit as a method is accurate and robust to large error but dependant on the correct selection of the look ahead distance – a distance too small results in a more accurate system, but makes the pathing more oscillatory, while a longer distance results in smoother pathing at the expense of accuracy to the desired route. This can be alleviated however with the implementation of a variable look ahead distance based on the speed of the vehicle, which allows for better performance at changing speeds. This comes at the expense of the risk of cutting or not seeing a corner at higher speeds due to the increased look distance, as well as steady state error due to the wider arcs the car is taking. [8]

This method was expanded upon with the Stanley method [9], which was first used in 2005 in the DARPA Grand Challenge at Stanford University. Stanley method improves upon pure pursuit by consisting of two terms which correct for angular error and distance from the desired path from the front wheel respectively (formula below) – by using the lateral distance from the wheel instead of using look ahead distance and generating arcs like in pure pursuit, the Stanley method avoids the danger of cutting corners as well as steady state errors, but can suffer from overshoot in turns and can be affected by disturbances:

$$\varphi(t) = \theta_p(t) + tan^{-1}(d_f(t) \cdot \frac{v}{k_v})$$

Where θ_p is angular error and d_f is the front lateral distance error, measured as the distance from the front axle to the nearest point on the desired path.

Model Based Controllers

Model based methods utilise a kinematic or dynamic vehicle model. Kinematic based control systems such as by B. Thuliot [10] work by decoupling the longitudinal and lateral dynamics of the car and performing calculations and correcting errors for each direction of movement, and are accurate and effective in low speed environments such as urban areas and when parking, however these models tend to break down at higher speeds as the added speed introduces additional complexities that make decoupling the two dynamics too difficult to do effectively. Cheung Jun Ma et al [11] proposed a Model Predictive Control algorithm that utilised both a kinematic and dynamic model to calculate steering control, and was found to be robust with a small tracking error. However, this method has a long convergence rate, limiting its effectiveness in applications which require higher speeds. Model based controllers, if done effectively, can improve tracking performance and can decrease reliance on the camera's vision distance, however it is reliant on having a high-fidelity model which is difficult to generate.

Feedback Controllers

Controllers based on feedback error are simple to implement and can perform well without a model and simply using incoming real world data. Pan Zhao et al [12] proposed an adaptive PID controller that could effectively follow paths that were predefined, and a steering controller developed by Kapina et al. [13] was effective at minimising lateral deviation from the path and maintaining vehicle stability even at handling limits. Feedback controllers are therefore extremely proficient at ensuring high handling performance at speed, which was utilised by Y. Chen et al [14], developing an optimised pure pursuit controller by combining it with a PID controller and a low pass filter to smooth the final steering angle, which improved tracking performance and reduced dependence on look ahead distance.

Steering Rack

To orient the wheels, a steering linkage can be used with a servo motor to angle the wheels. A method to link the steering to the wheels is simple steering, in which both front wheels are both rotated by the same amount – while easier to implement, a problem with this configuration is that the inner wheel in a turn completes an arc with centre point that is different to the outer wheel, which results in the slipping of the wheels and tyre wear as both wheels conflict with each other. An alternative to this is the use of Ackermann steering, which solves this problem by adjusting the linkage so that the inside wheel is further rotated to result in both wheels sharing the same arc centrepoint, eliminating the slippage and wheel wear that would occur in simple steering.

Racing Line

In general, racing lines for a majority of courses whether real world or virtual are designed by human drivers or by domain experts respectively [15], with few exceptions in commercial racing games such as Forza Motorsport, which uses evolutionary computation to improve racing lines [16]. Smaller open source games such as The Open Racing Car Simulator (TORCS) utilise a combination of good practises and heuristics to quickly generate a basic racing line for any track. Examples such as the K1999 algorithm [17] and work by J Quadflieg et al. [18] provide effective algorithms, however, all require prior knowledge of the track layout, which is unavailable to NXP competitors. Therefore, these methods will need to be adjusted in order to utilise the data available through the camera during the race.

Speed Control & Hardware [AH]

Traction & Drivetrain

There are two types of friction experienced between the wheels and road surface – static friction, when there is no slip between the two surfaces and kinetic friction, experienced during slippage. Static friction is typically greater than kinetic friction and so wheel slippage is undesirable [19]. The aim of the drivetrain setup is to maximise traction available to a vehicle. Traction is the maximum frictional force experienced before slippage occurs at the wheels. Increasing traction increases the torque possible at the wheels, to maximise the possible acceleration.

Traction for a single wheel is given by, $F_{max} = \mu_s F_n$, where μ_s is the coefficient of static friction between the road and the wheel and F_n is the normal force of the car acting upon a single wheel perpendicular to the road. From equating this with Newton's Second Law, the maximum possible acceleration from a single wheel is given by, $a = \mu_s F_n / m$, where m is the mass of the vehicle on that wheel. Assuming F_n is entirely due to gravity (g) then acceleration becomes, $a = \mu_s g$. From this it is clear that the only way to increase the maximum acceleration a single wheel can provide is to increase its μ_s. This can be achieved by using tyres made from softer materials and heating up the tyres before racing [20]. Additionally, in the hobby industry, adhesive compounds to apply to the tyre are available. Alternatively, adding downforce through aerodynamic means increases F_n without adding significant extra mass. This would increase the maximum possible acceleration.

While the above methods increase the maximum possible acceleration per wheel, the wheels can only be utilised for accelerating the car if they are driven. Undriven wheels distribute the total normal force exerted by the mass of the car, reducing the traction available to driven wheels and so resulting in lower maximum acceleration. Four-wheel drive (4WD) makes use of all wheels, at the expense of complexity and some mass for the additional hardware when compared to two-wheel drive (2WD). This makes 4WD a superior choice for maximising acceleration.

The competition rules state that off-the-shelf chassis can be purchased. Given the potential complexity and mechanical engineering involved, it would be out of scope to design and build one. 4WD chassis are readily available in 1/10th scale models for little extra cost. The competition guidelines state 1/16th as a recommended scale but very few suitable 1/16th chassis are available. However, the scale is only a rough grouping and 1/10th scale cars can be found with the same body length (300 mm) and similar wheelbase (longitudinal axel separation) as the recommended car kits. For a given maximum steering angle, only wheelbase affects turning radius. Car width is less important since two wheels are allowed off the track. Therefore, a 1/10th scale chassis could be acceptable.

Motor & Controller

Given that the system will be battery operated, DC motors are a logical choice. While brushed DC (BDC) motors were once popular being cheaper and simpler to control using a PWM chopper circuit or H-bridge, more recently, three-phase permanent-magnet brushless DC (BLDC) motors have become the dominant technology in high performance hobby grade robotics.

BLDC offers many advantages over BDC: greater reliability due to lack of brushes; higher efficiency due to lack of voltage drop across brushed contacts; higher power to size ratio due to better heat dissipation since the windings are around the stator rather than the rotor; flatter speed-torque characteristics (at rated load) due to lack of brush friction at high speeds; speed not limited by the mechanics of the brushes; reduced inertia since permanent magnets have less mass than windings; and reduced electromagnetic noise due to lack of commutator sparking. The trade-off is increased motor cost and increased complexity in the controller since a BLDC controller must compensate for the lack of commutator [21].

To calculate motor specifications, some understanding of the vehicle drivetrain is required. Most 4WD chassis available make use of front and rear differentials to reduce wheel slippage in corners. The differential allows wheels to rotate at different speeds, this is needed when cornering as the outer wheel will be following a longer circumference than the inner wheel. So long as no wheel has lost traction, motor torque is distributed evenly between all four wheels [22]. Assuming this, a peak current requirement can be calculated based on available traction. Overall torque (τ) is related to overall armature current (I_A) and motor velocity constant (K_V in RPM/V) below [23] [24]:

$$\tau = \frac{8.3 I_A}{K_V}$$

Equating this with the torque equation based on wheel radius (r), gear ratio determined by the number of teeth (T_p) of the pinion gear (motor shaft) and number of teeth (T_s) of the spur gear (differential shaft), and traction available at all four wheels gives:

$$\mu_s m g r = \frac{T_s}{T_p} \frac{8.3 I_A}{K_V}$$

In the above equation, $I_a$is the peak current since traction is the peak torque achievable before the wheels slip. Hobby grade BLDC motors are generally specified by their peak current and K_V values, with rule-of-thumb K_V and gear ratio recommendations for certain classes of car depending on battery voltage (higher voltage requires lower K_V) and what is available. These will be used when deciding final motor requirements.

BLDC speed control can be achieved with both open and closed loop controllers. So long as the load is reasonably constant and the speed/voltage is controlled, the motor will maintain synchronisation. However, variations in load (likely in a moving vehicle) could cause synchronisation to be lost and cause the motor to ‘snap’ in between commutation cycles [25]. Therefore, open loop control would be a poor choice for vehicle propulsion.

Constraining the controllers to closed loop, two variants are sensored and sensorless. Sensored controllers typically use three hall effect sensors in the motor to detect the current rotor position. This sensor data enables the controller to energise the correct winding. Sensorless systems do not use positional sensors, instead relying on detecting the back EMF produced when a rotor magnet passes an unenergized stator winding. While removing sensors reduces motor cost, this comes at the expense of increased controller complexity and performance limitations. Below a minimum rate, the motor is unable to generate sufficient back EMF to be detected. This is particularly noticeable at start up when sensorless controllers must effectively run in an open loop configuration – resulting in snapping. Further, the back EMF can only be measured at rates lower than the ideal commutation rate (for a given voltage). As well as a limited speed range, sudden changes in load can cause the motor to lose synchronisation [25]. Given the requirement to navigate complicated sections of the track at low speed, for a modest absolute price increase of around £20, a sensored BLDC (hereafter referred to as BLDC) system would be preferred. This reflects anecdotal evidence of their recommended use in hobby grade model cars.

While the design and implementation of a custom BLDC controller is possible, its increased complexity over BDC may be out of scope for the project. The competition rules also state that off-the-shelf controllers are allowed. Suitable hobby grade BLDC controllers can be purchased in the region of £20-£40. These can be configured to implement electronic braking and 'punch' which limits peak current and is essentially torque limiting, amongst other features. While good value, the precision and reliability of their control is unknown as documentation is poor. They also lack full customisation and cannot implement direct torque control. This could limit the level of control which the system has over the overall speed of the car and so increase lap times. Industrial grade controllers cost in the region of £100-£250 and do offer these features. However, industrial controllers are generally not designed for battery use and so many cannot run below 8 V, which is higher than the competition rules allow. Further investigation is required to choose a controller.

Speed Control Methods & Cornering

Given the project objective to reduce lap times, maximising cornering speed is critical to the success of the project. Speed control can be subdivided into determining the speed setpoint for the car and then maintaining this setpoint.

Calculating the maximum cornering speed around an unbaked curve is a straightforward kinematics problem. The traction available must be equated with the centripetal force based on curve radius (r), car mass (m) and velocity (v) as shown below:

$$\frac{mv^2}{r} = \mu_s F_n$$

Assuming the normal force is entirely due to the weight of the car then maximum velocity is given by:

$$v = \sqrt{\mu_s r g}$$

Assuming an ideal racing track will be received from the steering control module in the form of a polynomial, the radius of curvature of the track at any point $M(x, y)$, where $y = f(x)$, is given by [26]:

$$r = \frac{[1 + f'(x)]^{3/2}}{|f''(x)|}$$

This can be used to calculate a velocity profile to feed into the speed controller. Some scaling down would then be required to ensure a safety margin. This could be determined through trial and error once a vehicle is available.

The method of maintaining the speed setpoint will depend on the BLDC controller used. An ideal scenario would involve industrial controllers with torque control. Depending on the configurability of the device, either torque limits could be set and the device would maintain its own speed, or a feedback speed controller could be designed (such as PID) to work as the master device in a cascaded control setup based on speed control feeding into torque control [27]. However, as a hobby-grade device seems a likely scenario and given the poor documentation available for them, a precise plan would not be beneficial until such a device had been purchased and investigated.

Generating Downforce

In a full-scale vehicle, passive aerodynamic downforce can be generated provided the vehicle is traveling at sufficient speed. The model vehicle in the project will be limited to lower speeds however due to its power and the size of the track. It could be possible to actively generate downforce using a vertically mounted motor and propeller. These are readily available from the drone market and can easily generate in the range of up to 200 N of downforce, a similar level of normal force generated by the mass of the car. As previously derived, maximum acceleration is proportional to the normal force and so could be dramatically increased. Maximum cornering speed is proportional to the square root of normal force and so a more modest increase would be expected.

Such a vehicle would comply with competition rules so long as only one motor was used for vehicle propulsion, bringing the total to two. Alternatively, an electric ducted fan motor (EDF) could be used from the model plane market to increase safety by containing the propeller within a duct.

There could be concerns with gyroscopic effects generated by the propeller as well as the yawing movement in reaction to the rotating airflow generated. However, these could be counteracted using a contrarotating pair of propellers and a simple planetary gearing arrangement to drive them in opposite directions. Further, EDFs contain stator fins to stabilise the rotating airflow. This leaves the main concern being added mass and raising of the centre of gravity of the vehicle. Further investigation would be required into the effectiveness of such a system, especially given the lack of any precedent being found by the author in research or in the hobby community online.

Torque Vectoring

Vehicles tend to understeer when entering a corner at high speed. Understeer is when traction is reduced at the front wheels causing the front end to slide out of the corner back towards a straight trajectory and so is inherently stable. With only weaker kinetic friction acting on the wheels responsible for steering, the radius of the turn is increased which leads to poor handling. Without any corrective systems, speed must be reduced so as to not exceed the static traction of the wheels.

Torque vectoring (TV) is a method whereby additional forward torque is applied to the driving wheels on the outside of a bend and less torque is applied to the inner wheels, in order to impart a yawing moment on the vehicle and enable it to maintain a tighter trajectory though a curve. This helps limit oversteer and so a higher speed can be maintained through corners [28].

For electric vehicles, new opportunities for TV are available which were not practical with internal combustion (IC) vehicles. Many opt for four motors, each driving a single wheel. This enables high control over the torque applied to each wheel, more so than the active differentials and single motor setup of many IC vehicles. However, additional motors add mass to the vehicle, reducing handling. Additionally, the competition rules prohibit more than two motors. Using active differentials is also a highly complex mechanical problem and such devices are not available for model cars. A simpler form of TV is however possible – brake torque vectoring (BTV).

TV operates most effectively when the friction at the wheels is approaching saturation, at this point BTV begins to operate. The brakes at each wheel can be independently actuated, and so the brakes on the inner driving wheels are applied to impart a negative torque. Simultaneously, motor power is increased and due to the braking applied to the inner wheel, the differential transfers an equally opposite torque to the outer wheel, in a similar fashion to a limited slip differential [28] [22]. The application of power prevents a speed reduction which would otherwise be caused by the application of brakes. This process generates a yaw movement into the bend. BTV has been found to be similarly effective as active differentials, if less efficient due to energy loss from braking [28].

A yaw rate controller is required to control the level of TV, which is commonly achieved through PID control and the use of a gyroscopic sensor. An additional side slip controller can be used in case the level of friction at the wheels is overestimated, to limit the level of side slip. However, sensing this and then implementing a control algorithm is complex [29]. Given the predictability of the track and vehicle setup used in the competition, this precautionary controller should not be necessary.

A BTV setup for the model car is possible. 1/10th scale disc brakes, actuated by a servo motor via a cable, are available for model cars. Anecdotal evidence suggests that positioning them on the wheels is a poor strategy since steering and suspension movements can pull the cable and activate the brakes. A better method is to position the brakes at the differential, which is fixed to the car chassis. However, redesign of certain chassis parts may be required to fit the brakes in the limited space available.

Work Programme of Tasks

Computer Vision [HS]

1. Choose and order processor boards and camera
    a. The board must use exclusively NXP processors
    b. The processor must be able to run computer vision near to real time
    c. The board must be able to interface to an NXP or non-processed camera
    a. The processor must be able to directly or indirectly drive two PWM signals
2. Get processor running with camera and basic computer vision
    a. Flash the compute board with an OS
    b. Connect the camera to the board
    c. Read the camera input using the computer vision package
3. Create computer vision steering control interface
    a. Create code to communicate to ESCs and servos
    b. Create code to drive wheels to position and speed of desired line
4. Create Hough based line detection algorithm
    a. Test different blurs, edge detections and masks for Hough line detection
    b. Calculate the centre line of these and feed this into the control interface
5. Test automated driving
6. Create region based corner control
    a. Test different blurs and edge detection techniques
    b. Test different methods of detecting different track pieces
7. Test automated driving
8. Create mapping/stitching algorithm
    a. Research methods of implementation
    b. Implement the method
9. Create line and speed optimisation algorithm
    a. Try different racing line algorithms
    b. Try different speed algorithms
10. Create true position algorithm

a. Use computer vision or sensors for true position algorithm
b. Implement Proportional or PID control of true vs desired speed/position

11. Integrate and test
12. Additional improvements time (Agile iterations)
    a. Improve each aspect of the implemented algorithms using trivial or original methods. This may take advantage of rules or track specifics.

Steering Control [DC]

1. Servo motor selection and order
2. Mount to steering rack
3. Source simple controller and implement steering angle control
    a. Calibrate the servo position to wheel angle precisely
4. Develop basic centre-line pathing with computer vision to interface with steering
    a. Build simple straight-line track with single corner
    b. Detect track edges and calculate centre point
    c. Generate and display path using centre points.
5. Develop and investigate initial feedback controller with centre-line pathing
    a. PI or PD controller to follow centre-line with fixed speed
    b. Tune controller to avoid over/undershoot
6. Develop and investigate initial path tracking algorithm
    a. Initial algorithm will be based on Pure Pursuit with fixed look ahead distance
    b. Test algorithm with fixed speed (Display arc calculated if motor control unavailable)
    c. Investigate with various look ahead distances
    d. Implement look ahead distance proportional to speed
    e. Test algorithm with fast and slow speeds on straight track.
7. Develop and test Pure Pursuit combined with PI controller
    a. Tune controller to avoid over/undershoot
8. Integrate with rest of hardware and test

Speed Control & Hardware [AH]

1. Chassis selection and order
    a. Selection should be based on car length in relation to recommended frames
    b. Should be four wheel drive with Ackermann steering
    c. Should be possible to add disc brakes for torque vectoring
    d. If wheels are available which provide more traction than stock chassis wheels then these should be purchased
2. Motor / speed controller selection and order
    a. Motor specifications should follow those recommended for similar vehicles at hobby grade racing level for sensored motors
    b. Measurements taken from wheel to estimate coefficient of static friction
    c. Above specifications should be used to calculate a current requirement for the motor and speed controller
    d. Choose a speed controller which features braking, sensored operation and torque limiting
3. Interfacing with speed controller and investigating controller properties to maintain set speed
    a. Select microcontroller suitable for speed control – this could be the same controller which is used for computer vision, or a parallel controller which runs steering and

speed control in a real time environment, unaffected by the complexities of computer vision
    b. Establish the range of programming options possible with the speed controller purchased
    c. Experimentally determine the level of control offered if not specified in controller datasheets (i.e. is true speed control possible)
    d. Establish communications from microcontroller to speed controller
4. Implementing variable speed and motor braking in relation to track curvature
    a. Investigate how and when to apply braking
5. [SECONDARY OBJECTIVE] Research active downforce system using propeller/EDF units
6. [SECONDARY OBJECTIVE] Implementing torque vectoring hardware
    a. May require 3D printing of replacement chassis parts
    b. Will require research into which form of brake discs are required and which servos to control them with
7. [SECONDARY OBJECTIVE] Implementing torque vectoring (TV) control system
    a. Determine when vehicle requires TV
    b. Investigate other sensors to limit wheel lock from braking (perhaps hall effect sensors on the wheels)
    c. Measure yaw rate likely with gyroscope
    d. Research and implement yaw control system to aid steering

Project Plan [AH]

Task	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
[ALL] Complete PID	*																				
[ALL] Research/order uproc, camera, chassis, and wheels																					
[ALL] Configure compute module and camera, assemble chassis																					
[AH, DC] order servos, motor & controller based on chassis & wheel grip investigation																					
[HS] Create line detection algorithm																					
[DC] Implementing initial steering control algorithm																					
[AH] Implementing speed decision																					
[ALL] Register for competition							*														
[ALL] Interfacing uproc, speed controller, servos & adding to car																					
[ALL] Interim presentation								*													
[ALL] Testing car and refinement																					
[ALL] Interim report										*											
[DC] Add feedback control to steering, implement racing line algorithm, object avoidance																					
[HS] Optimising vision, object detection, speed detection																					
[AH] Look at adding downforce, torque vectoring and speed response to objects																					
[ALL] Testing and refinement																					
[ALL] Final presentation																			*		
[ALL] Thesis																				*	
[ALL] Competition																					

Risk Register [HS]

As a method of reducing risk in the project, a risk register is formed to plan possible foreseeable issues and their ability to be prevented or mitigated. Each risk is identified and explained with current in place systems which is then given a risk rating based on the likelihood and severity of the risk. If this risk rating is too high or can be mitigated additional measured should be implemented to reduce this risk. A residual risk rating is then calculated in the same manner. Risks can then be prioritised in group work and meetings to reduce the risk of project failure.

Hazard summary	**Existing Measures**	**Likelihood**	**Severity**	**Risk Rating**	**Additional Measures**	**Residual Likeli-hood**	**Residual Severity**	**Residual risk rating**
Data Loss	Software created for the RC car will use cloud based version control (gitHub) allowing for simultaneous code writing and secure cloud storage.	1	4	4	N/A	N/A	N/A	N/A
Over Budget	All purchases must discussed as a team and also approved by supervisors before the PO is submitted	2	4	8	Purchases made and planned must be entered into the budget spreadsheet	1	3	3
Time Limits	Use the gantt chart as a rough guide for project expected timeline and base progress according to objectives.	3	3	9	Follow an agile methodology where basic requirements are met first and then implemented and improved iteratively.	2	3	6
Rule Breakage	All members have a functional understanding of the rules for the car before, and during car design and programming.	2	4	8	Use a condensed rule sheet for car design specification to check against. A full review should also be run before car submission to check all rules are met.	1	4	4
Car Breakage	A redundant safety system is planned to predict and prevent car crashes from out of control errors	1	4	4	N/A	N/A	N/A	N/A
Lost time injury	Risk assessments should be read and followed to prevent injury that may lead to lost time injuries. Lost time from illness cannot be reasonably mitigated.	2	2	4	N/A	N/A	N/A	N/A
Hardware issues	Stick to gantt chart for design and look for external help if running off schedule. Use propper handling with electronics especially LiPo batteries or any CMOS or static sensitive devices.	2	3	6	N/A	N/A	N/A	N/A
Software issues	Use unit tests to automate testing as well as following a agile methodology to improve software iteratively. Plan to log car data to know what's happening in the automated code.	3	3	9	N/A	N/A	N/A	N/A

Risk Rating Reference

	Likelihood				
Severity	**1**	**2**	**3**	**4**	**5**
1	1	2	3	4	5
2	2	4	6	8	10
3	3	6	9	12	15
4	4	8	12	16	20
5	5	10	15	20	25

Risk Rating	**Explanation**
1-5	No additional measures needed but can be implemented to reduce further risk.
6-12	Decide whether further measures need to implemented to lower risk rating.
15-25	Stop the corresponding task(s) immediately and seek to reduce risk.

Table 1: Preliminary Risk Register

Risk Assessment [HS]

Generic risk assessments are already in place for lab work, including desk work. A formal risk assessment is to be made around the use and storage of LiPo batteries but is yet to be submitted. A project risk assessment has been created to cover all risks associated to the project whilst removing redundant hazards such as chemical usage. Here an identical approach to rating risks is applied as above in Table:1.

Potential Hazard	Potential Harm	Existing Measures	Likelihood	Severity	Risk Rating	Additional Measures	Residual Likelihood	Residual Severity	Residual risk rating
Soldering	During soldering the heated element may burn the user if used incorrectly. The soldering iron could also start a fire if on around flammable objects. Fumes from burning may also be hazardous to health. This may affect all people using the soldering irons or those working nearby or in the event of a fire everyone in the building.	Soldering irons have finger guards to stop slippage onto the hot element, stands are also provided to hold the iron whilst not in use. Safety glasses must be worn whilst soldering to protect from spitting solder. Extractor fans and windows should be used to expel fumes from soldering. Irons should be turned off after use.	4	1-3	4-12	Be sure to use solder long enough that fingers aren't close to the element. Grippers should also be used with flying leads or easily moved devices. The stands should be inspected before use to make sure no flammable contents are inside.	1	2	2
Electricity	Most devices are connected to 240V mains which could lead to anything from a simple shock to death if contact is made. Our project uses 2S LiPo batteries at a max of 8.4V, this has little electrocution risk. This could affect all users of the room including cleaners.	All devices in the lab must PAT tested. This should be checked as well as a visual inspection of all mains connected devices.	2	2	4	N/A	N/A	N/A	N/A
Tools	Hand tools may lead to entrapment, small cuts or bruises from misuse or dropping. Small flying waste material may also damage eyes. This may affect users and nearby workers.	Eye protection should be worn when using tools that may give off waste material. If possible waste should be protected from flying away. If not trained with a tool, ask a competent person for an introduction.	1	2	2	N/A	N/A	N/A	N/A
LiPo	LiPo batteries may catch fire if charged incorrectly, stored incorrectly or physically damaged.	If the battery deforms, is damaged or impacted it must be disposed of as directed by the local health and safety officer. The battery must be under constant supervision whilst charging as well as exclusively using approved charging circuitry. When stored the battery must be kept in a metal tin filled with sand.	2	4	8	N/A	N/A	N/A	N/A
Desk Work	Desks, computers and chairs each have the ability to cause longterm harm from bad habits. RSI from keyboards. Back problems from chair posture and eyestrain from computer screens. This could affect the user.	Breaks should be taken from computer work to reduce eyestrain and back issues. Chairs should be adjustable with armrests and setup correctly.	1	4	4	N/A	N/A	N/A	N/A
RC car	The RC car could be a trip hazard whilst moving or not. The RC car could also damage items on or around the floor if hit at high velocity.	When testing the RC car on the floor warning should be given to all nearby personnel.	3	2	6	The RC car should also have a redundant safety system to disable the car in case of lost control.	1	2	2
Slips Trips and Falls	Boxes, cables and spillages may act as vessels for slips, trips and falls leading to scrapes, bruises, broken bones or concussion.	lockers and under desk storage are available to store project items and bags/coats whilst in the lab. Spillages should be reported and protected/signposted whilst being cleared.	3	2	6	N/A	N/A	N/A	N/A

Table 2: Preliminary Risk Assessment

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Appendix

Authorised user Risk Assessment sign off Sheet

By signing this sheet you are stating that you have read, understood and agree to abide by the SOP, risk assessment, COSHH & MSDS (if applicable) listed below

Your Name: Andrew Huff

Supervisor's Name: Jiabin Wang & Luke Seed

Risk Assessment ID	Signature	Date of reading	Supervisor signature	Date of Authorisation
EEE-GRA-003 Lab Risks	[signature]	22/10/19	[signature]	22/10/19
EEE-GRA-00 Office Based	[signature]	22/10/19	[signature]	22/10/19
EEE-GRA-001 Soldering and Circuit Construction	[signature]	22/10/19	[signature]	22/10/19

Authorised user Risk Assessment sign off Sheet

By signing this sheet you are stating that you have read, understood and agree to abide by the SOP, risk assessment, COSHH & MSDS (if applicable) listed below

Your Name: David Chung

Supervisor's Name: Jiabin Wang, Luke Seed

Risk Assessment ID	Signature	Date of reading	Supervisor signature	Date of Authorisation
EEE-GRA-003 Lab Risks	[signature]	22.10.2019	[signature]	22/10/19
EEE-GRA-00 Office Based	[signature]	22.10.2019	[signature]	22/10/19
EEE-GRA-001 Soldering and Circuit Construction	[signature]	22.10.2019	[signature]	22/10/19

Authorised user Risk Assessment sign off Sheet

By signing this sheet you are stating that you have read, understood and agree to abide by the SOP, risk assessment, COSHH & MSDS (if applicable) listed below

Your Name: Hamish Sams Supervisor's Name Jiabin Wang

Risk Assessment ID	Signature	Date of reading	Supervisor signature	Date of Authorisation
EEE-GRA-003 Lab Risks	H. Sams	22-10-19	Jiabin Wang	22/10/19
EEE-GRA-00 Office Based	H. Sams	22-10-19	Jiabin Wang	22/10/19
EEE-GRA-001 Soldering and Circuit Construction	H. Sams	22-10-19	Jiabin Wang	22/10/19