DTU Solar Car : Design of Light Peripherals

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Abstract - The DTU Road Runners team is producing a car driven purely on solar energy, dubbed the Solar Car. This paper focuses on the design, development, and construction of essential peripherals in order for the Solar car to pass inspection. The paper revolves around producing a light system for the car that is within the minimum requirements set by the law, that can fit onto the chassis without compromising the aerodynamics, and all that while being power efficient. Programs applied for the project involve Fusion 360 and KiCad. The paper illuminates the design and construction phase of PCB modules controlling the lights around the car. The project had an extensive construction phase with a lot of trial and error in order to get a working system in the end. A description of all the reflections achieved during this phase will be in the discussion and reflections, along with an extensive reflection on the brainstorm and limitations of the project. The proposed system aims to provide a comprehensive solution for lighting, while complying with legal regulations, enhancing safety, and improving the overall driving experience of the solar car.

I. INTRODUCTION

The DTU Roadrunners solar team is designing a solar car with plans to compete in both the Bridgestone World Solar Car [9] and iLumen challenge [10]. They have to create a car that is solely powered by electricity obtained from solar panels and manual recharge. The car earns points based on various factors, ranging from energy consumption to simple practicalities.

We have been assigned the task of improving and expanding the car's peripherals to enhance its practicality. Since practicality is subjective, it is our responsibility to research and determine which peripherals would offer the most practical value and then incorporate them into the car. To participate in the Bridgestone World Solar Car challenge, the car must also comply with road legal requirements set by the Australian government [2]. Additionally, as the car will undergo a test drive from the northern part of Jylland to Sjælland in Denmark, traversing the entire country, it is imperative that the car is legally drivable in Denmark as well [3].

Problem statement

The overall aim for our project is to improve the driving experience of the DTU Roadrunners Solar Car by developing the cars peripherals,

- **What goes into the driving experience?**
  - How are normal cars designed when focusing on driving experience?
  - Why is it important that the driving experience is good?
  - Which peripherals would help make the driving experience better?
- **What are the laws and rules that the car must comply with?**
  - How do the point system work for the different competition?
  - What are the national laws for a car and the design we are making?
  - How does the rules of the competition differ from national laws?
  - What are the rules concerning peripherals?
- **How do we improve driving experience while still maintaining a low power usage and stay within the rules?**
  - How can we achieve an equilibrium between the driving experience and the power spent on achieving said experience?
  - What peripherals would be best to implement relative to both driving experience and power usage?

Limitations of our problem

Our peripherals were limited to only working on the light compartments.

II. PROJECT IDEA AND INITIATION

We started our project with a brainstorming phase. Our aim is to enhance the driving experience of the solar car by developing its peripherals. Firstly, we brainstormed quality-of-life peripherals that we had encountered in regular cars. Our brainstorming session was extensive and covered a wide range of ideas. Subsequently, we referred to the Solar Car Wiki [7] to understand the current state of the car and identify aspects that could be improved or developed to address our problem statement while assisting the team in achieving their goals. After reading the wiki and discussing with the team, we discovered that the car was still in the early stages of development. Therefore, we agreed to focus on essential peripherals to make the car drivable.

Following our research, we embarked on a second brainstorming session to explore essential peripherals we were interested in working on. This led us to consider light compartments or position sensors. To further refine our direction, we decided to meet with the solar car team and discuss their thoughts and ideas regarding which peripheral would be sensible to work on. Although sensors offer significant value for the driving experience, we decided to continue our efforts, in collaboration with the team, with brainstorming a solution for light compartments and other smaller peripherals, as these were necessary for getting the car on the road. Our initial ideas revolved around developing the following lights for the car.

- Front light compartments, this includes
  - Low beam lights
  - High beam lights
  - Daytime running lights
  - Position lights
- Rear light compartments, this includes
  - Braking lights
  - Fog lights
  - Reverse lights
  - Rear lights
- Indicators

Now we could end our idea and brainstorming phase since we had created an overview of what we had hoped to accomplish.

III. PROJECT DEFINITION AND PLANNING

After narrowing down our project and identifying our focus, we began discussing our plans and desired end product, as well as the necessary steps to achieve it. Our goal was to develop all the lights required for the car to pass inspection. The Solar Car utilizes a CAN-Bus system to collect and distribute signals. To ensure full functionality, we needed to communicate with this system by incorporating Arduinos inside our light compartment boxes. These Arduinos would facilitate information exchange with the CAN-Bus, and part of our project involved writing the appropriate code for this interaction. In order to meet inspection requirements in Denmark, we needed a comprehensive understanding of mandatory car lights, including rules regarding light placement, deflection angle, and brightness.

Having provided an overview of our project's integration into the overall car setup, let's now explore how we plan to design the lights and the compartments themselves. To accomplish this, we will utilize the Fusion 360 program, which allows us to visualize how the lights will appear on the car and identify any design constraints that must be adhered to for proper integration.

Next, let's delve even deeper into the realization of our lights. After receiving signals from the CAN-Bus and transmitting them to the Arduino, indicating that a light should be activated, we will create a module consisting of PCB boards. These PCB boards will convert the received signals into illumination for the appropriate bulbs. To design this module and the PCBs, we will utilize KiCad 7.0.

Research

A part of working on a project that has been going for a while is you need to make sure that you have the full understanding of what the current state of the project is. Therefore we approached the Mechanics team, who also work on the car, so we could see how the current chassis looked and how we could fit lights onto it.

We also researched what the battery output for the cars battery was, here we found out that we had a voltage source of nominal 12V, meaning that if we needed 5V we would have to convert the power our selves.

As previously stated the Solar Car communicates through a CAN-Bus system, in order to extract the proper information for lights and sending the correct responses we need to know what signals we can expect to receive and therefore also the ones we should be sending back. The CAN-Bus input plug supplies a High Signal, Low Signal, VCC (12V) and Ground. We are going to be supplying that to a CAN-Bus Shield which converts it to Rx and Tx signals which are the ones the Arduino uses as input signals.

Moving onto the rules and regulations, in the next section we will go into further details about what our research culminated in with regards to the danish laws. In our process of researching what laws we would have to comply with in order to be eligible for the two challenges we found that for the challenge in Australia there were no extra requirements compared to danish law, other than it being mandatory to have fog lights on the back of the car in case of sandstorms[9]. For the iLumen challenge in Belgium the car will be on a closed off circuit and therefore the rules are way more lenient.

Law and technical requirements

Looking at the danish national laws for road cars, we found that some of them were decently explained and some of them were poorly explained and not clear

enough for a lot of the requirements.We believe we have all the required light that is necessary for a car in Denmark to be road legal. These can be seen in a resume by following the reference link. [11]
These were the rules and regulations that were coherent enough to make us understand the minimum requirements set by the law. For the ones we were not able to fully understand or we needed clarification on, we contacted "Færdselssytrelsen", which is the administration in charge of traffic, transportation laws, the inspection of vehicles, drivers licenses and more. We corresponded with them via email and phone calls with a vehicle inspection inspector.
After summarizing our notes gathered from emails, documents and our phone call with the vehicle inspection inspector, we created a small compendium of the laws and regulations so we always had an overview available.[11]

Challenge requirements

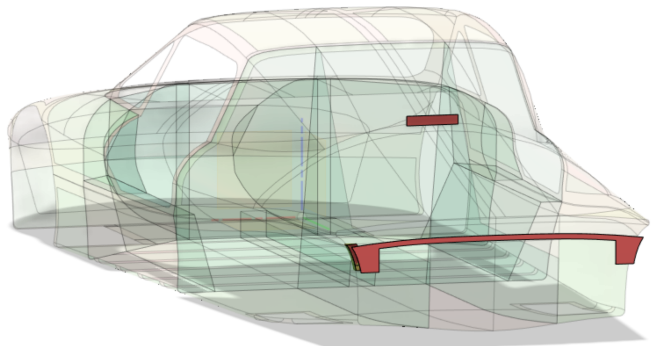
As aforementioned the aim for the DTU Solar Car team is to participate in both the iLumen European Solar Challenge and in the Bridgestone World Solar Challenge. For the iLumen Solar challenge the car will be going around on the former F1 Track called Zolder, it is 4.011km long. In the challenger class the winner will be the car that drives the furthest within 24 hours, you are allowed to charge the car with the officials twice. There are also points being dealt for some aerodynamics testing and the fastest lap, but distance ridden is the majority of the points.[10]

Now for the Bridgestone challenge, the challenges resemble each other quite a lot but in Australia the course is a long journey all the way from Darwin to Adelaide which means traversing Australia from top to bottom. The winner will be the car that first arrives in Adelaide, recharging is allowed at two spots designated by the organizers.[9]

IV. DESIGNING THE PROJECT

After having defined the goals and workflow for our project, and aligned them with the challenge requirements. We are now ready to begin the work itself. Starting with a design phase.

We wanted to create an overview of where the light compartments would actually be place on the car. We corresponded with the mechanics team who provided us with a step file that we could upload to Fusion 360 and then visualize how the lights would look.



Figur 1: A Fusion 360 sketch of the car

In the figure[1] you can see that the solid blocks are the light compartments we are aiming to produce. For our rear lights we will be using continuing LED-strips, these strips will both be the rear lights, the rear indicators and also the lights for reversing and braking. As aforementioned the LED-strips will also be used for reversing, here we will be producing a white light in the middle of the strip. At the top of the car you can see our braking exclusive light, this light will only turn on when the car is braking.

Indicators & Hazard lights

For the indicators we also use sets of LED-Strips, here we would like to design an "animation"so the LED's in the indicators turn on sequentially and then reset. This would produce a nice smooth flow to the light. Indicators have been placed at the rear, sides and as a part of the driving lights as well. When we turn on the Hazard lights it will enable all the indicators simultaneously.

Headlights

For the head lights we had to approach the design very differently than we had first wanted to, prior to our inclusion in the Solar Car project there had been made a sketch for how the chassis was expected to look and due to the calculations regarding the aerodynamics for said chassis it was very hard to change. It was not possible to find a head light compartment that would fit all three parts of the head lights. The chassis was too low to meet the requirement for minimum distance above ground and the angles of vision. Fixing this issue would have required substantial changes to the front of the car[8].

PCB Modules

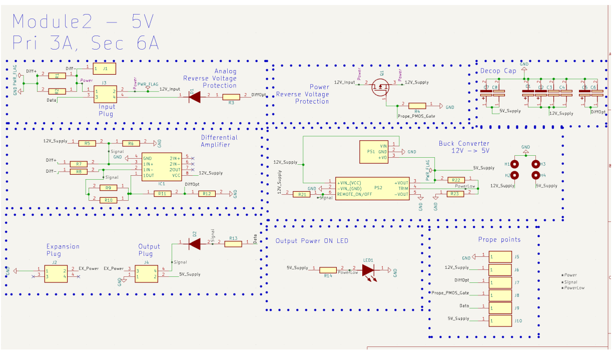
When designing the PCB's we wanted both the ability to supply 12V and 5V. That's because we need different voltages for the the headlights and the other lights. For

[1]Note that it is only the rear part of the car, at the time of sketching the mechanics team had the full responsibility for the headlights.

the LED-strips where we need 5V[5]. Since the lights consist of varying number of LED's there will be a different power output attached to it. This results in us having to use different types of converters depending on how much power is expended. For the lights that require a substantial amount of power we use a DC-DC converter, whilst when current and therefore power is low we use a linear regulator. The Arduino requires a small current and therefore we use a linear regulator instead of a DC-DC converter. The reason we even use the linear regulators is because they are small and cheap. The Arduino has a built in linear regulator itself[4], but it may become hot and might damage the Arduino over time. Therefore we chose not to use it.

The Buck-converters we use when the power is high, since the output voltage is more stable and it does not convert the power to heat like a linear regulator would. We do not use a Buck converter for the Arduino, mainly because it is large and quite expensive. So whenever possible we would like the option of using linear regulators instead.[4]

Our Arduino is limited by how much current it can draw, therefore for our 12V board we send the digital signal from the Arduino to a gate driver, which can draw more current. This gate driver we use to control an NMOS, which we use as a switch for the headlights. The 5V board we digitally control with a data signal, we pass this signal through a resistor and diode so there is no risk of a short circuit and over-voltage from the output pin.



Figur 2: The schematics for our 5V module

By danish law [11] the car is required to display an error when the light system for the car is non functioning. This we have chosen to verify by monitoring the power consumption with a differential amplifier[4] for all of the individual current loop. For this we have chosen to measure the voltage drop over a power resistor to calculate the current draw. We have chosen resistors, that gives a gain of 20. We will always have the high voltage on the non-inverting input, so we will never get a negative signal, this means we do not have a need to connect a bias.

In case somebody mistakes VCC and ground, we have implemented a PMOS for reverse voltage protection, so it does not damage our PCB[4].

We have chosen to split up our PCB in modules, with a "Master module", 12V-module and a 5V-module. This decision was made for several reasons. We need several 5V and 12V boards, because each light needs a fuse and power supply each. So even though we use a long LED-strip, we split it up electronically to give each a separate power supply. So each brake light has it own power supply and each rear light has it own power supply and so on, this is to make sure that no side of the car potentially has a blackout. This is mandatory per danish law[11]. Hence it became convenient to create separate modules. That way if you choose other lights, that need either 12V or 5V, you just have to change one module and not every PCB. This also makes it cheaper, which is also one of the reasons to split it up in modules. If the size of the PCB surpasses 10X10cm^2 it will result in the price increasing exponentially.

Arduino code

To control the light we get a signal from the CAN-BUS, which we then supply to an Arduino Nano. This will be the brain of our system and supply our light modules with the proper data. The master module will be sending status signal back to the CAN-BUS, these status signals will provide the information about the state of the lights through an analog reading. This means that it is possible to compare the actual state of the light with the expected based on our input signal. Doing it this way however does not provide information on why a light might not be working only that it is not doing what we expect. Troubleshooting will therefore require a manual check.

The signal we receive to the Arduino from the CAN-BUS is the same for both turning on and off. This means that we can minimize the amount of different signals we would need to send, as the appropriate light instead changes state from on to off or opposite. The indicators are coupled to the *millis()* function, that makes use of the real time passed since the program was turned on. This means that we can have the indicators function without causing delay for the rest of the program. To control that the signals are doing as expected, we are making use of a digital low pass filter[6], to filter the values such that we can create a break point for the LED's turning on or off. This allows us to be more precise when reading our analog signals.

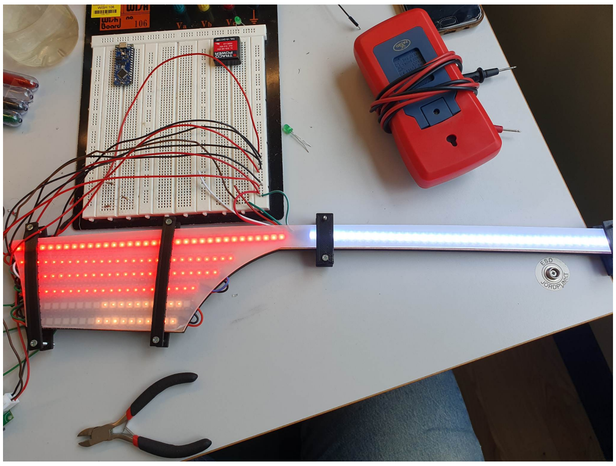
V. TESTING THE PRODUCT

After being satisfied with our designs and choice of components we had the opportunity to gain a understanding of what roughly the power efficiency of our system would be.

For our LED-Strips we looked at the corresponding data sheet and found the following: Every LED lights up with the RGB colors, we can tune the different values to choose the color we want displayed with our Arduino signal. The power usage of each LED light is 0.1W per color that it shows, this means that if we tuned one value to 255 it would require the most amount of power, being 0.1W, and if we turned say one of the values to be half it would require half the power, meaning 0.05W. It is a linear scale. When testing our components we found there to be an uncertainty of approximately 10%, therefore the actual power consumption is 10% higher for the LED-strips[5]. There are some requirements when it comes to light intensity in order for the car to pass inspection, light intensity is measured in the unit candela[11]. Looking at our data sheets we find the maximum candela output for our LED-strips[5], by tuning the RGB values we can decrease the light intensity and save power. However we do unfortunately not posses the proper equipment for validating the theoretical light intensity. Testing the power efficiency of our modules, we found that the "master module"used 0.3W. The change in power from standby and active is negligible. For our 12V board the standby power used is 0.1W and when it is active it uses 0.37W. For the 5V board it uses 1.4W, this is always active, since the strip integrated circuits requires 5V for communication.

Finalized design

After a couple of reevaluations of the lights, the PCB and the code, we ended up with a final product that functions properly. Our finalized product however has room for improvement.



Figur 3: A picture of the finalized product

VI. REFLECTION & DISCUSSION

Overall reflections

This section exists to give a complete overview over the thought process and the learning's that we had during the course of the project.

Initially when we began the project we had hoped to engage in more peripherals around the car than just the light compartments. Adding sensors we felt would greatly have improved the driving experience as well. However for the reasons listed below we could not get around to it in this project. In the interest of complete transparency we found often during the course to be a bit stumped by just how much work was required in developing the light compartments from scratch. Of course we could have completed the light peripherals with much less time if we bought pre-made lamps and our only addition would be to provide the proper signal. We felt that diving deeper into the construction of the lights would make our project more nuanced and comprehensive and therefore also more educational. Enhancing our own skills in soldering, drawing PCB layouts, identifying components, and research only became possible with this prioritization. For this course we wanted to obtain a fine balance between making sure our project had substance enough whilst also being able to provide a finished product to aid the Solar Car team, this we felt was the aim with the course.

The problems that followed with this balance were that sometimes we would spend more time than expected researching laws and technical regulations, which proved to be quite a hassle, instead of focusing on the pure electrical parts of the lights.

Technical reflections

Our system has some flaws and thresholds for when it looses operation. We use the function "*millis()*"in our Arduino code for the blinker lights. This however means that the car needs to be restarted every 50 days, as that is the time it takes for the function to overflow and reset back to 0[1].

We did not implement a safety for the case where a higher than intended voltage input plug gets connected to the output outlet on the 5V board. We planned to do it for the 12V module using a solid state relay. However they were either too big or needed AC on the output to turn off. Therefore we decided to try and make our own relay, here we used PMOS's with their sources connected together, soon however, we realised that to get the right gate-source voltage. We would need to get the source to around 12V, but it has to be galvanic isolated from the supply, which was inconvenient to implement. Therefore we decided to not have any safety and just use an NMOS that goes to virtual ground. The output and input of the 12V board should be 12V on both, this should not damage any component. For the 5V board, the only thing we risk of damaging is the buck-converter, which is the compromise we reached.

With the known resistance, we use to measure the current, we control whether the light are on. We actually have a way to check, how much power the light is using. We did not implement the software to calculate the power and send a signal back. But if you are interested in knowing the power of each light, it is easy to implement.

For the power we use decoupling capacitors to filter and obtain a more stable input voltage, due to the nature of how a buck converter has a switching frequency that creates noise on the power rail. The data signal that has almost no current, we want to use a lowpass filter to remove noise. We misunderstood the difference between power and data signals, so we made room for decoupling capacitors on the data signal traces, which would not work. This is why we use a digital lowpass filter in the Arduino. For the PCB we chose to use a lot of through hole components, which require a lot of space on the board, we could maybe have minimized the PCB by using surface mounted components instead. This would however be harder to solder on making the process longer.

Discussion

One of the most important parts in designing the solar car is power management and efficiency. For both the challenges that the car aims to participate there are tough rules on recharging, making the power consumption and the solar panels generation essential. The ambition for our project was to limit just how much power our light system would expend in order to have the smallest effect on the driving efficiency as possible, however after multiple conversations with our technical supervisor and the Solar Car team we were assured that creating a light system that was fully working would be the first priority. The power efficiency would be the second priority, since we could always look on optimisation later on.
A long way into the progress of designing the solidwork file and the design of the light and PCB, we had another conversations with a vehicle inspection inspector, who said that either we have to buy lights that are already approved for a car or we had to get them approved. The LED-strips we had chosen were not approved for road cars. So when the car gets inspected, the lights will need to be approved for road cars. This is not impossible, but since we do not have the equipment to do all the measurements prior to the inspection, we can not confirm the data from the data sheet or our calculations, and therefore it has to be done before that. If the Solar Car team decides, that they do not want to invest time and money into getting these lights approved, they will have to find some lights that already are approved. We have designed our system in a way, that modifying the system should be easier than the previous system created. They can also just use normal LED-lamps, since we have room for both an extra outlet and another data line for another LED-strip which might require two data lines.

VII. PROJECT FINALIZATION AND CONCLUSION

Rounding up our project we have managed to produce a fully operational electric part of the light system for the Solar car, the product we leave behind is fully ready to be implemented on the car with the corresponding code that we have made. It is now up to the mechanics team to find shells that can fit our modules and LED-Strips and fit it onto the car.

We have obtained substantial knowledge about the technical regulations in order to get the car to pass inspection for the light system, this knowledge we used when deciding parameters like position, light intensity and choice of lamps.

In this paper we also describe how you could optimise the power efficiency of the setup, this is an open invitation for the team to do so.

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