

THE NORTHERN MEN TECHNICAL REPORT

NXP Cup EMEA Finals 2017

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Introduction

The goal of the NXP Cup is for the student team to build autonomous car that can navigate using optical sensors, identify the race track and finish the course without leaving the track. The teams are made from university students and all team must oblige to the requirements and the limitations of the contest. The winner team is the one whose car completes the track the fastest.

Our team, The Northern Men is made up out of two students from the Hanze University of Applied Sciences in Groningen: Rinalds Kugis and Dirk Jan Snippe. We are in the second year of the four-year bachelor program Sensor Technology.

The project was supervised by: Felipe Nascimento.

Mechanical Design

The starter kit contained from the chassis, linkages, two DC motors to power the back wheel, a servo motor for the steering, 7.2VDC 2000mAh NiCd battery and a Freescale Linear CCD sensor. No changes to the starter kit were made, but camera mast and a 3D printed plate to which microcontroller is secured were connected to the chassis. The camera mast is made from an PVC tube. The camera and tube are mounted to the car using 3D printed parts. Next to the camera on the same PVC tube the lights are mounted. the lights are made out of 20 white LEDs that are placed on a 3D printed bar to evenly distribute them over the width of car.

We have a 7.2VDC 3000mAh NiMH battery as a backup battery that can be placed in the car instead of the starter kit battery if the 7.2VDC 2000mAh NiCd battery stops working properly.

Other parameters of the car are:

Width	16.5 CM
Height	30.0CM
Length	28.4CM
Weight	

Table 1 dimensions car

PCB shield for Kinetis KL25Z microcontroller

The Kinetis KL25Z microcontroller development board is used for the car. we designed a PCB that fits on top of the PCB ourselves. It contains H-bridges, power regulator, connectors for servo motor, camera and control circuit for the lights. The PCB layout is displayed in the Figure 1. The schematic of the PCB is showed in the Appendix 2.

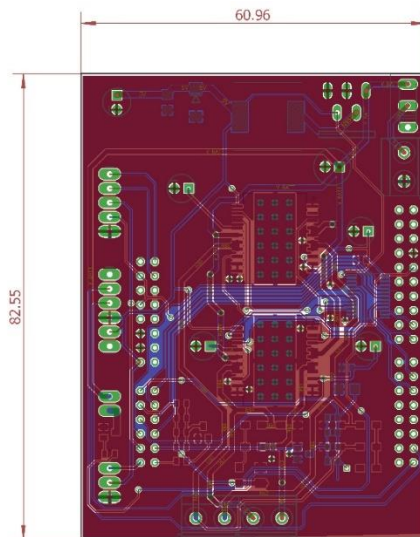


Figure 1. PCB layout.

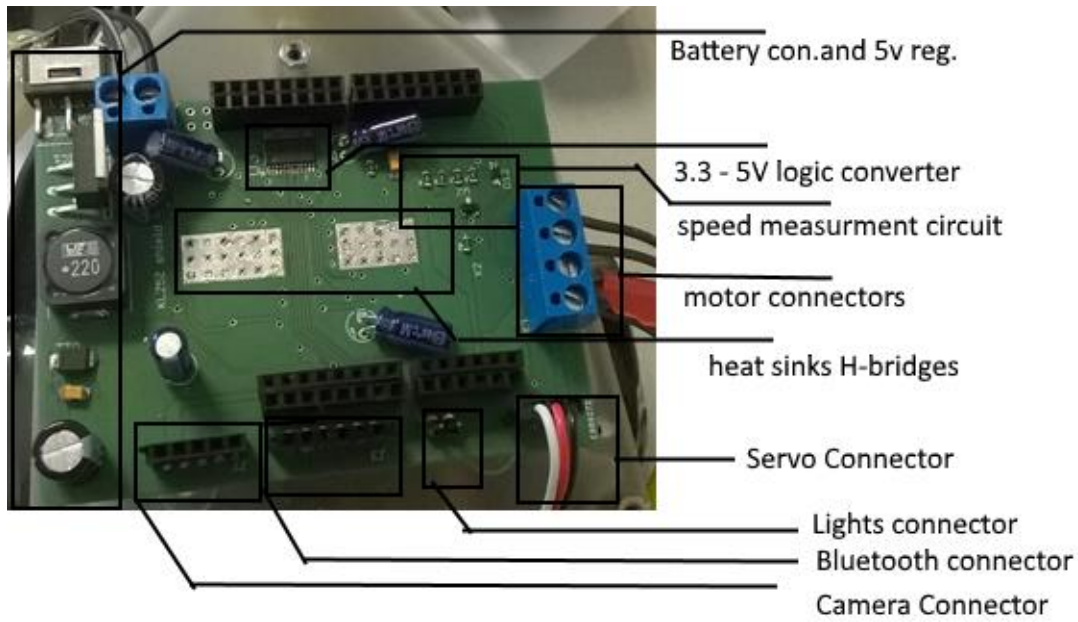


figure 2 Top side PCB

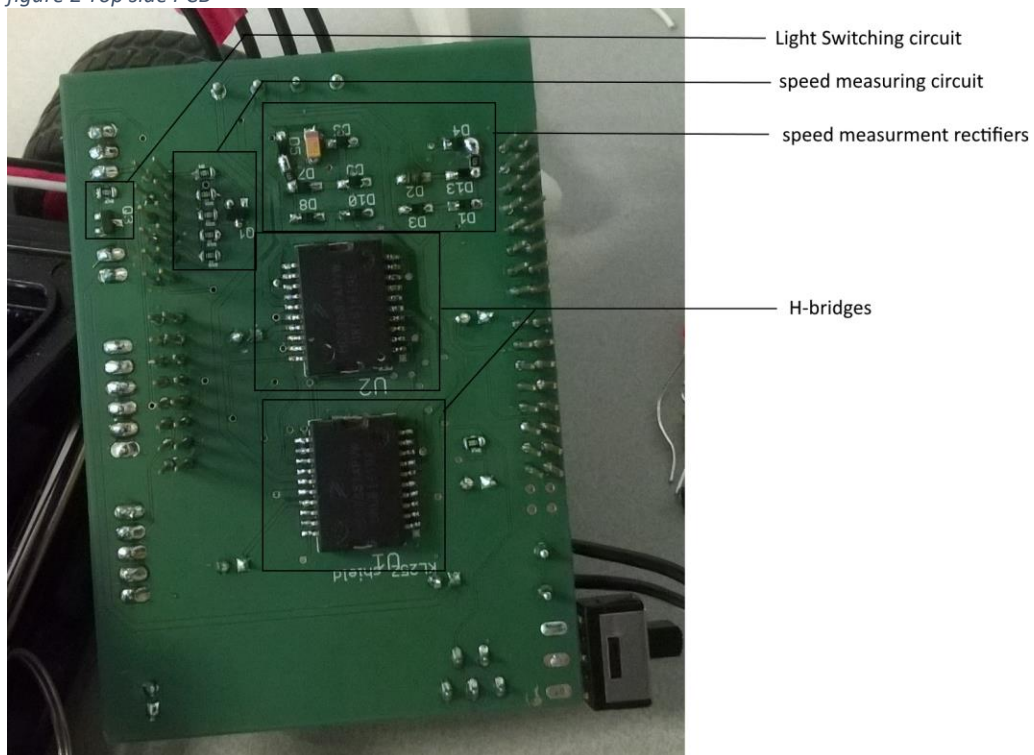


figure 3 Bottom side PCB

Sensors

In the car, a total of 3 sensors are used. These sensors are:

- 2 Current sensors
- 1 Camera.

Each of these sensors will be discussed in its own paragraph. Because when the PCB was made it included a circuit which could measure the speed they are shown in the pictures. The circuit however had problems and the components were removed for the finals.

Current Sensors

The current sensors are used to measure the current going to each motor. The current sensor is the feedback (FB) output of the H-bridge. This output provides $1/375^{\text{th}}$ of the current going to the motor [1]. A resistor is used to convert this current to a voltage which is read by the ADC. a capacitor is added over the resistor to smoothen the voltage ripple caused by the PWM of the motors.

Line scan camera

The NXP Cup Community page [2] was used to understand the basics of the line scan camera. The Freescale TSL1401CL CCD sensor [3] was used for this specific car. It has resolution of $1\text{px} \times 128\text{px}$. The camera is made from 128 photodiodes, RC circuit, shift register and switches. The basic idea is that each pixel is connected to the RC circuit with a switch and depending on the colour/light reflected from the surface the charge after specific time will be different for different colours. If camera is not read for some time the RC circuit charge is too large and interferes with reading so it has to be reset before accurate readings can be done. The camera outputs each pixel value as an analogue value. To control the camera two pins are used: SI and CLK. By toggling SI pin high the shift register is reset so the first pixel can be read. To move from one pixel to another clock signal is applied to CLK pin. The CLK is connected to the shift register that shifts the bit by one pixel to the right on each rising CLK edge. When the bit in the shift register is high the corresponding switch for the specific pixel is closed and its value can be measured. Camera's sensitivity to the light can be adjusted by changing the camera clock frequency.

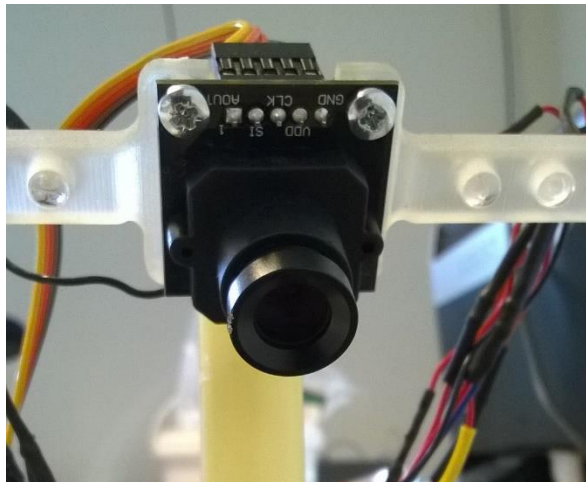


figure 4 the Freescale Line Scan camera

Program

The program of our NXP Cup car can be divided in three part: image acquisition, image processing and car actuator control. The car must navigate only using optical sensors and it is crucial to obtain representative image from the camera to be able to do further calculations and adjustments with the actuators. Once the image is obtained, it is analyzed in the image processing part to determine the position of the track. Afterwards, the actuators of the car are adjusted accordingly so the car stays on the track.

For our NXP Cup car the Landzo Devil Linear CCD sensor [3] is used as the optical sensor. The linear CCD sensor is greatly affected by the changes of the light intensity of the environment as if the lights are brighter the values obtained for each pixel are higher than for a situation when camera clock is at the same frequency, but the overall light intensity is lower. If the clock signal frequency is set constant, there can be situations when sensor is so insensitive with a higher light intensity that there are no observable differences between the pixels capturing the white middle of the track and the black sides or with a lower light intensity significant differences can be observed between two pixels capturing the white colour in the middle of the track. To achieve greater accuracy of the image recognition algorithm when detecting the white middle and the black lines of the track the values describing each specific colour in each image should be as close as possible to the value which describes the specific colour in other images. The image was considered within the standard if the value of a white pixels was equal to possible maximum value \pm the tolerance (normally 2%, but can be adjusted for specific conditions to achieve the best result) and the black parts had the pixel value of less than 80% of the maximum possible value. In this kind of standardized images, it is possible to find the black borders of the track with the needed accuracy.

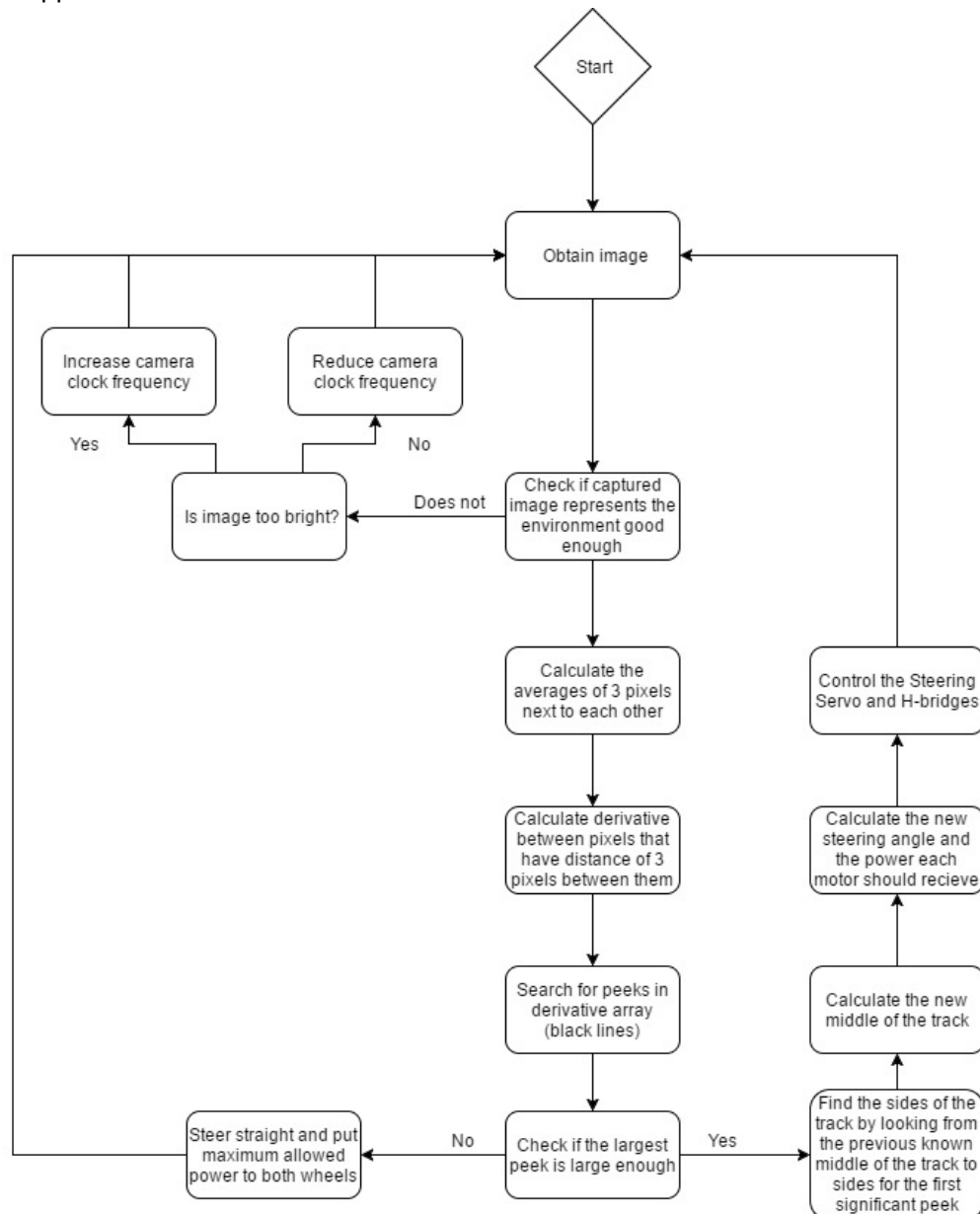
To obtain standardized images, the camera clock frequency was adjusted continuously. An array with approximately 10 (the size can be adjusted to achieve the best results in the specific conditions) different camera clock frequencies were obtained during the testing of the camera in different light conditions. When the image is captured it is checked if it fulfils the requirements set for the standard image and if not, new image is captured using higher or lower camera clock frequency positioned in the frequency array next to the current one. This approach guarantees that the optimal frequency will be found most commonly with zero to two adjustments and in the worst-case scenario with as many adjustment as big is the frequency array (10-12) as each next camera clock frequency in the array was chosen to have significant effect on the image captured when compared to the previous one.

Analog to digital converter (ADC) was adjusted on the KL25Z board to achieve faster ADC conversion rate. To do so low-power mode was disabled, ADC clock was set to BUS clock, ADC Clock divisor was set to 1 and short ADC sample time was chosen.

Once a standardized image is obtained it is processed in the image processing part. First, derivatives are calculated for each two pixels standing next to each other. Afterwards an array is made from the sums of three neighboring derivatives that are used to decrease the effect of the camera noise to the calculations. An average absolute derivative value is calculated from all sum derivative values that have absolute value bigger than zero. Taking the position of the previous middle of the track as the base point closest derivatives to the left and the right, that are larger than the average absolute derivative value, are found and are considered to be the positions of the left and the right black lines. From these two positions the middle of the track is found.

When the image has been analyzed and track found in it, the program goes into the car actuator control part. First the steering angle of the car is adjusted. The error (track middle point offset from the middle of the car) is fed to a PID controller that is responsible for the steering angle. The set point for the PID controller is to reach a situation when the middle of the car is in line with the middle of the track.

Second, the speed of the car is adjusted. If finish is detected the car is set to break until the lowest threshold of the speed sensor is reached and the motors are turned off completely. If finish is not yet reached, the steering angle and the second order derivative for the current and previous middles of the track is calculated and used to determine if car is driving on the straight, going in or out of the corner. When car is going in to the corners there are three possible states in which the motors can be that are selected depending on the speed: full power, power is reduced for both motors with bigger reduction for the inner wheel or the car is breaking. If car is driving on the straight or going out of the corner full power is applied to both motors.



Physical interface

During the race the program parameters can be only adjusted using the on-board interface. For this reason, a physical interface was created using an LCD screen and three buttons – UP, DOWN and

SELECT. SELECT button is used to switch between the parameter list and the parameter's value. The UP and DOWN buttons are used to choose the needed parameter and change its value. The parameters that can be adjusted in this way are the maximum power applied to the motors, proportional and integral coefficients for the PID controller and the maximum speed in the corners.

Bill of materials

Bill of materials can be seen in Appendix 1.

Results

We built a real size test track to be able to test the car. Each individual part of the track was made separately from paper. This approach allowed us to relatively easy change the configuration of the track. The pieces were held together with transparent tape and the track was held down with heavy objects to prevent the track from shifting. For example, long straights where car can reach the maximum speed and corner afterwards, continues 90° corners and so on. The hill was made from hardboard plate and wood. The tunnel was made from carton with wooden supporting construction. In order to test different light conditions, we took advantage of building's light system with which it was possible to dim the lights and the light intensity is kept at this level automatically by the building management system.

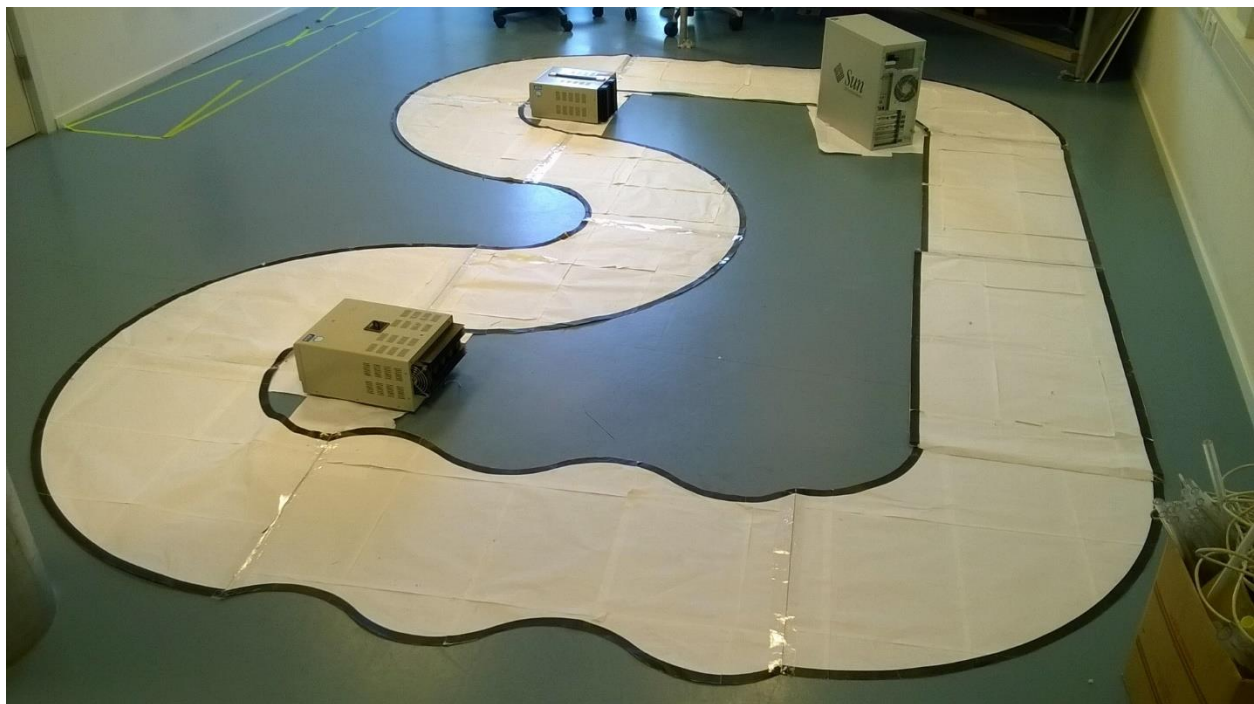


Figure 5. Test track

Conclusion

An autonomous car was designed and built for the NXP Cup that can complete the NXP track. The main focus was placed on cost effective, relatively simple and fast design and algorithms. The car was designed to work with the KL25Z microcontroller. An improvement in the future could be switching to

more powerful microcontroller, for example, Kinetis K64F or Kinetis K66F. Another improvement would be addition of wheel encoders and use of the CCD two-dimensional camera instead of the line scan camera. In this case more advanced algorithms could be applied and used that potentially could improve the performance of the robot car. However, with each additional part added to the car the system gets more complicated and requires exponentially more time for proper testing.

References

- [1] NXP Semiconductors, „datasheet MC33887,” 19 December 2017. [Online]. Available: <http://www.nxp.com/assets/documents/data/en/data-sheets/MC33887.pdf>.
- [2] G. Xiaoli, „Line Scan Camera Use,” NXP Cup Community, 24 04 2013. [Online]. Available: https://community.nxp.com/docs/DOC-1030#jive_content_id_1__Avoid_Light_Noise.
- [3] NXP Semiconductors, „NXP Community,” NXP, 2016. [Online]. Available: <https://community.nxp.com/docs/DOC-1058>.

Appendixes

Appendix 1. Bill of Materials

Qty	Value	Device	Parts	Manufacturer
1		255SB	S1	KNITTER-SWITCH
20		LED5MM	D1, D2, D3, D4, D5, D6, D7, D8, D9, D10, D12, D13, D14, D15, D16, D17, D18, D19, D20, D21	Betlux Electronics Co.,Ltd
1		3x1 pinheader	J4	Unknown
1		5x1 pinheader	J2	Unknown
1		4x1 pinheader	J3	Unknown
2	100	0.3OHM-1/8W-1%(0805)	R6, R16	PHYCOMP
10	100	100OHM1/10W1%(0603)	R1, R2, R3, R4, R5, R7, R8, R12, R13, R14	PHYCOMP
1	10uF	10UF-6.3V-20%(1206)	C8	AVX
4	1K	0.3OHM-1/8W-1%(0805)	R9	PHYCOMP
1	22uH	WE-PD-744770122_1260/1245/1280/1210	L2	WURTH ELECTRONIC
1	470uF	CAP_POLPTH2	C7	Unknown
4	47uF	CAP_POLPTH2	C1	Unknown
1	680uF	CAP_POLPTH1	C10	Unknown
1		FRDM-KL25Z	U\$1	NXP/Freescale
1	LM2596T	LM2596TV	IC1	Texas Instruments
2	MC33887APVW	MC33887APVW	U1	NXP/Freescale
3	Motor2Connector	MKDSN1		Unknown
1	PMV20XNE	BSS123	Q3	NXP
1	SN74LVC8T245PW	SN74LVC8T245PW	U3	NXP
1	STTH4R02U	DIODE-DO214AA	D11	ST
3	SWITCH-MOMENTARY-2PTH	SWITCH-MOMENTARY-2PTH	S2, S3, S4	Unknown

1		PCB		Eurocircuits, custom design
1		Camera	Not On PCB	Freescale
1		Car chassis	Not On PCB	Landzo
1		Servo	Not On PCB	Fatuba

Appendix 2. Schematic of the PCB shield

