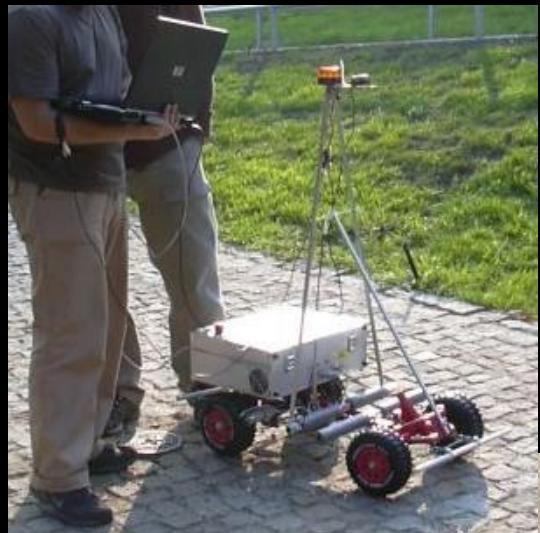


Istrobo*ti*c*s*

Robotour 2020, 3.2.2021

Pavol Boško, Radoslav Kováč

2007



2008



2009



2014



2015



2016

2017

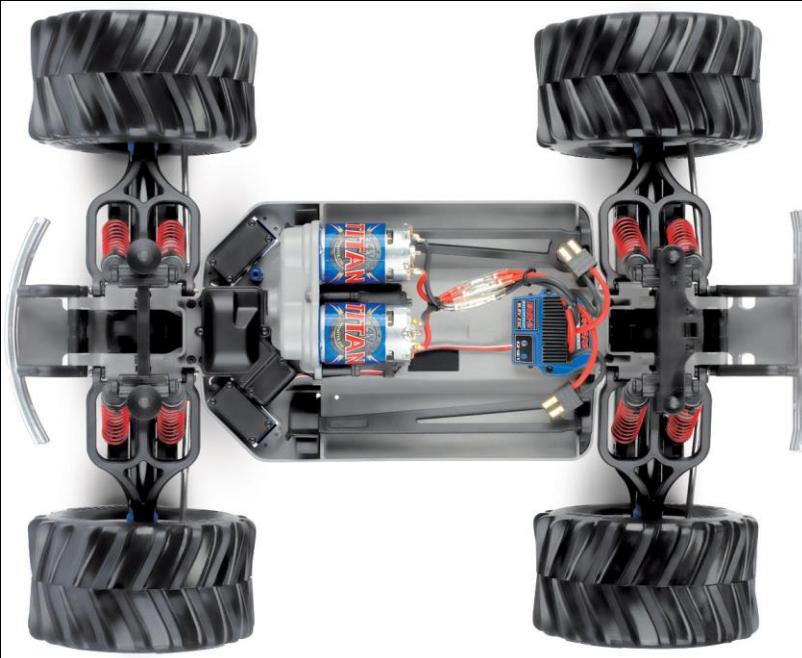
2018

2019

2020



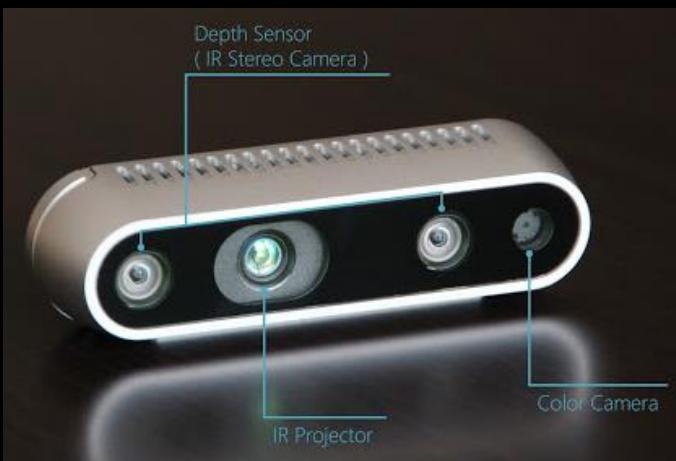
ROBOT CHASSIS



- RC model: Traxxas E-Maxx 4x4 monster truck
- Top Speed: 48 km/h
- Waterproof electronics, servos



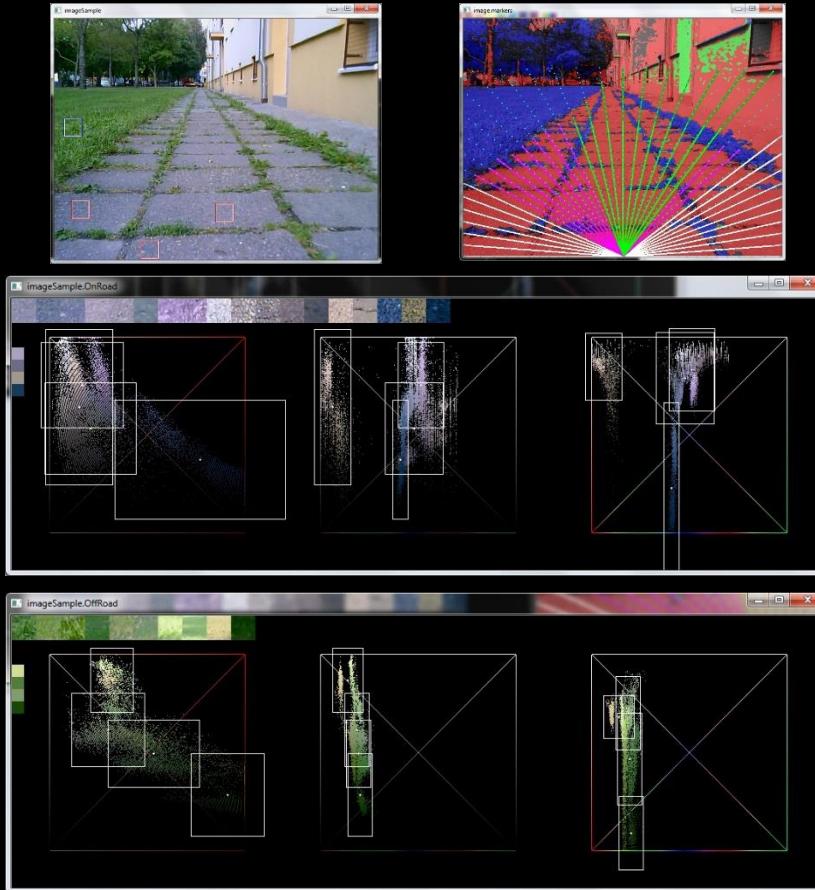
HARDWARE



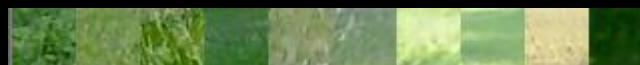
HW Component	Price
Chassis: Traxxas E-Maxx 3903 • Two Speed Conversion Kit, Gear, Shock Set...	440 Eur
Jetson Nano: 1.4GHz 4-core, 4GB RAM, 64GB SD • Arduino Mega: 16MHz, 8KB RAM • 2x Arduino Nano: 16MHz, 2KB RAM • Arduino Pro Mini: 16MHz, 2KB RAM	200 Eur
Depth Camera: Intel RealSense D435 • 2019: Odroid oCam 5MP (640x480, 170 FOV) • 2018: Odroid USB Cam (640x480, 65 FOV)	260 Eur
2D Lidar: RoboPeak RPLIDAR 360, 7Hz, 1° res. • 2019: Sick TiM571, 15Hz, 0.3° res. (\$2400)	100 Eur
GPS/Glonass receiver: Holux M-215+	40 Eur
Compass: Bosch BNO055	40 Eur
Baterries: 2x Antix HV-LiPo 9000 mAh, 7.6V	160 Eur
Ultrasonic Distance Sensor: 5x Sonar: HC - SR04	10 Eur
Other: LCD & OLED displays, 8x LED, Wireless NIC...	50 Eur
TOTAL	1 300 Eur

VISION (2016 – 2019)

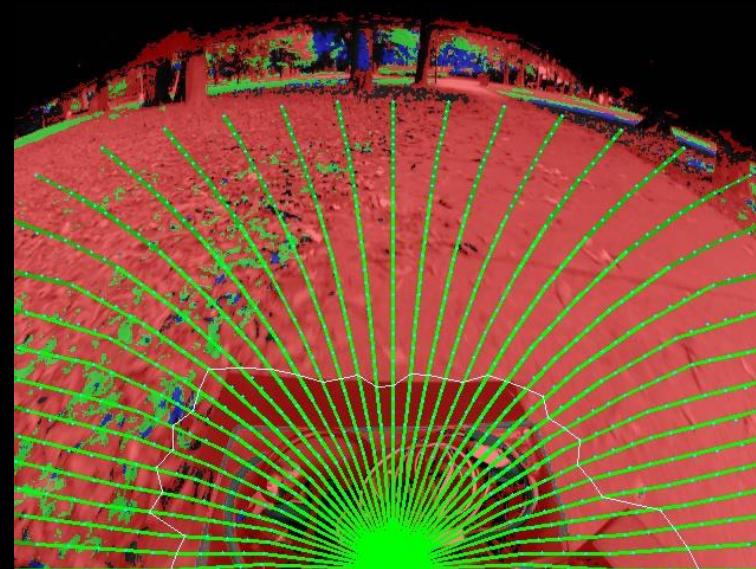
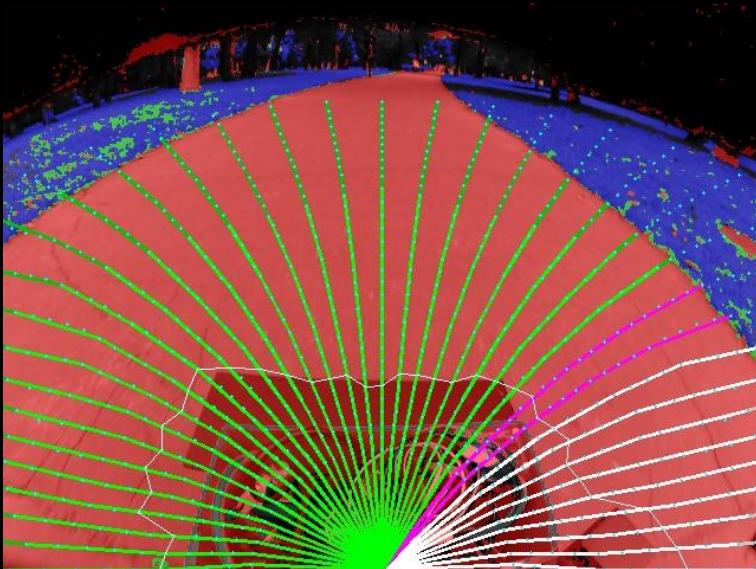
Pixel color classification



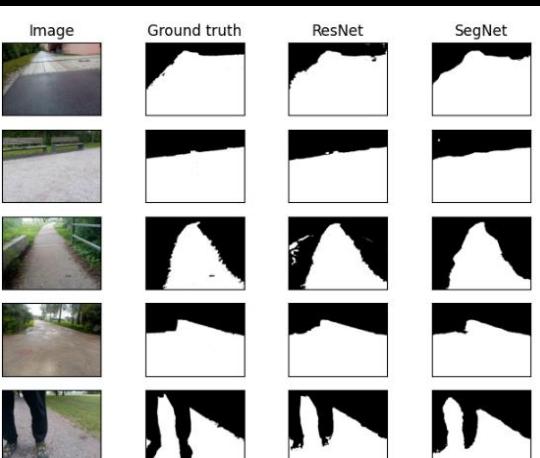
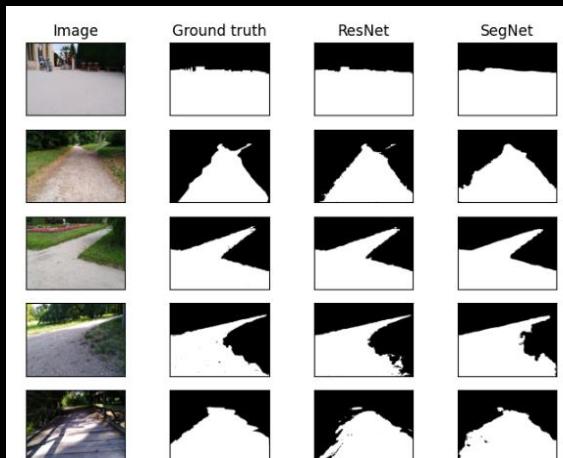
- Our old approach:
 - Classify every pixel as: road / off-road (grass)
 - Manually chosen samples (32×32 pixels)
 - Find nearest cluster in HSV color space
 - Lookup-table could be used: RGB \rightarrow class
- Disadvantages:
 - Adding more samples to improve the result was more and more challenging
 - brown leaves (in autumn) could not be distinguished from road



...IMAGE SEQUENCE #1



NEURAL NETWORKS at Robotour

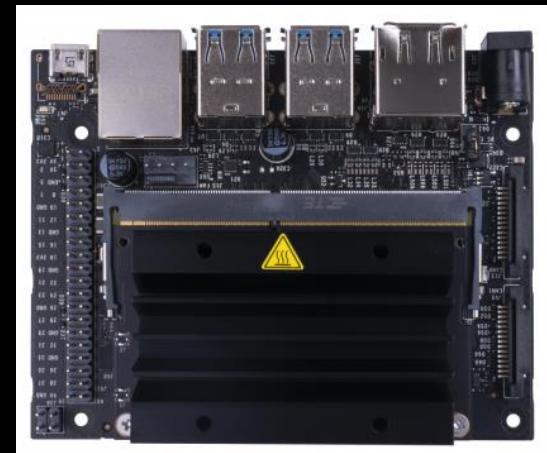
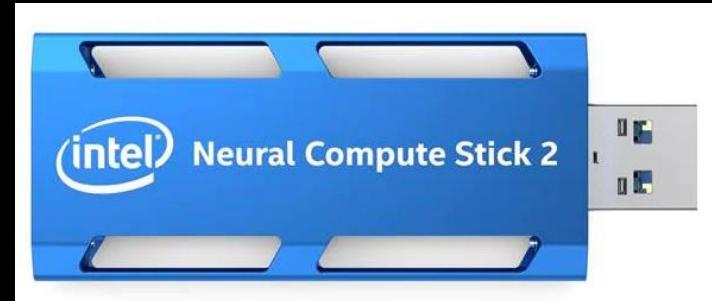
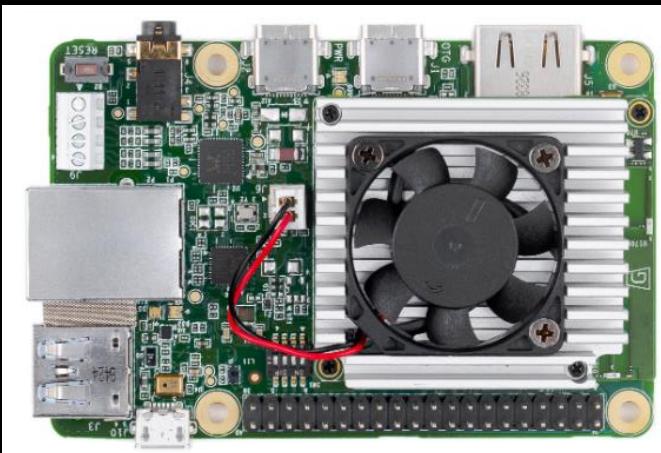


- 2014 – Smelý Zajko (SK), Plecharts (CZ)
 - first robots with neural networks
- 2016 – JECC (DE)
 - first convolutional neural network (CNN)
- 2019 – Smelý Zajko (SK)
 - <https://github.com/Adman/road-segmentation>
 - Adrián Matejov, Master's Thesis 2020 [1]
 - Jetson TX2: Tensorflow, Keras, Python
 - ResNet: 2,7mil params (33 MB), 240ms prediction
 - 2 datasets: 677 images, Lednice + Deggendorf
- 2020 – we used NN from Smelý Zajko
 - Jetson Nano is 2x slower than Jetson TX2
 - ResNet (f=4): 179.297 params, 200ms prediction
 - TCP between Python server and C++ client

AI ACCELERATOR HARDWARE – Google, Intel and NVIDIA [2]

Board	MobileNet v1 (ms)	MobileNet v2 (ms)	Idle Current (mA)	Peak Current (mA)	Price (US\$)
Coral Dev Board	15.7	20.9	600	960	\$149.00
Coral USB Accelerator	49.3	58.1	470	880	\$74.99+\$35.00
NVIDIA Jetson Nano (TF)	276.0	309.3			
NVIDIA Jetson Nano (TF-TRT)	61.6	72.3	450	1220	\$99.00
Movidius NCS	115.7	204.5	500	860	\$79.00+\$35.00
Intel NCS2	87.2	118.6	480	910	\$79.00+\$35.00
MacBook Pro ¹	33.0	71.0	1570	1950	>\$3,000
Raspberry Pi	480.3	654.0	410	1050	\$35.00

¹ The MacBook Pro takes a +20V supply, all other platforms take a +5V supply.

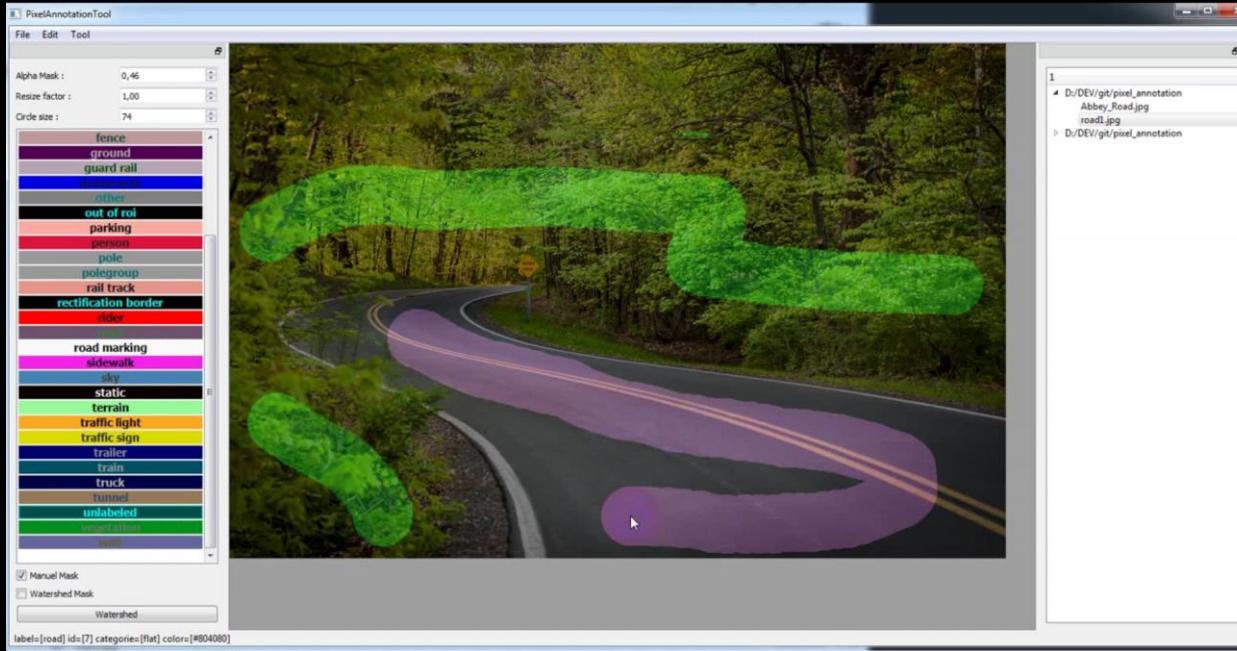


IMPROVING THE DATASET



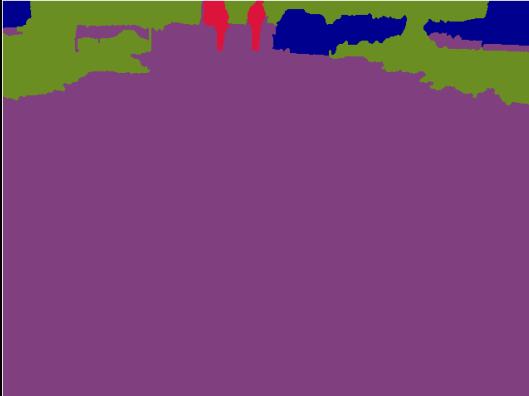
- What to improve?
 - Imperfect predictions on training images
 - grass-only images are missing in training set
 - images with walls are rare
 - test in different parks / locations / season
- Our database of driving data (logs, images)
 - 14 different parks (7x Bratislava, 3x CZ, 1x DE)
 - 50 driving days, 400 attempts
 - 500.000 images, 220GB data
- Identifying new images for labeling – our approach:
 - let the NN process images from past competitions
 - then manually select images with bad predictions
 - manually label / annotate new images
 - start NN training again

LABELING - PixelAnnotationTool



- PixelAnnotationTool
 - manually provide markers with brushes
 - then launch the algorithm
 - refine/correct the markers
 - markers are stored as separate images
 - Implements OpenCV watershed algorithm
 - marker-based image segmentation
- <https://github.com/abreheret/PixelAnnotationTool>

HOW TO ANNOTATE?



- More categories – more time for labeling
 - 2 categories: 90-120 sec / image
 - 10 categories: 180-600 sec / image
- What is the definition of “road”?
 - how about stairs? holes? filled with water?
 - curbs? seen from top? separate roads?
 - grass on road vs moss
 - definition: drivable from the robot position(?)

car (1)
other (2)
person (3)
pole (4)
road (5)
road marking (6)
sidewalk (7)
sky (8)
terrain (9)
unlabeled (0)
vegetation (Ctrl+1)
wall (Ctrl+2)
water (Ctrl+3)



no_road (1)
road (2)
unlabeled (3)

OUR TRAINING DATASET



- We annotated 540 new images (road/noroad):
 - CZ, Písek, Palackého Sady: 103 images
 - SK, Bratislava, Sad Janka Kráľa: 206 images
 - SK, Bratislava, Park Andreja Hlinku: 106 images
- <https://github.com/lrx-git/istro-rt>
 - dataset\image, dataset\masks
- incl. 2 datasets created by Smelý Zajko (677x)
- Data augmentation for NN training
 - blur
 - contrast
 - horizontal flip
 - crop: scale 3/4 + shift (top/bottom, left/right)
 - grayscale
 - positive effect – needs to be further evaluated [3]

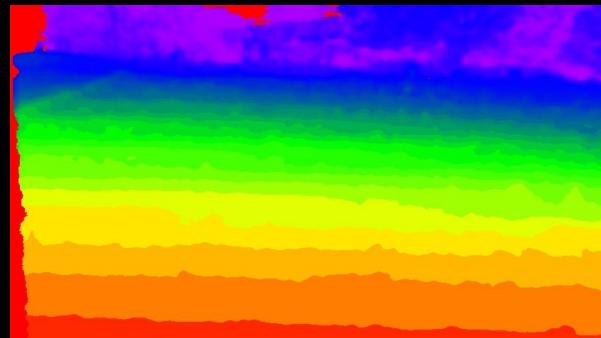
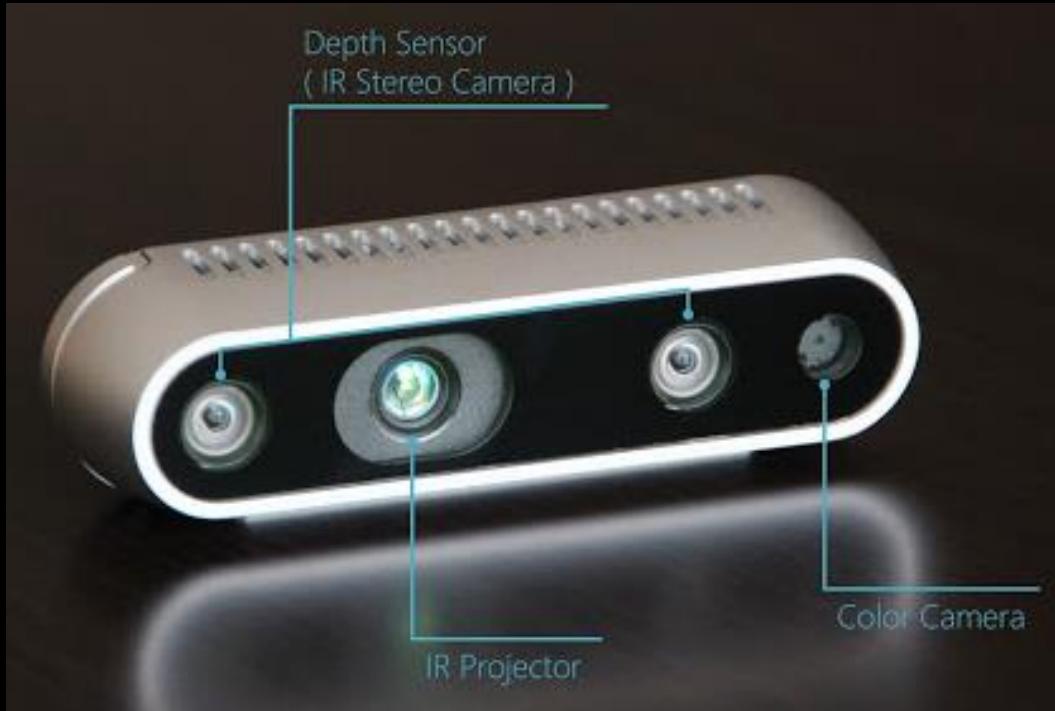
NEURAL NETWORK RESULTS



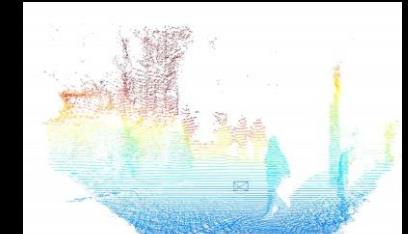
- Works nice
 - autumn colors are no longer a challenge
 - good(?) performance with grayscale images
- Ready for "Klondajk" (Robotour 2020)?
 - problems with grass on concrete roads
- Grass covered with snow?
 - No way – snow makes it impossible to find road
 - additional training images will be needed



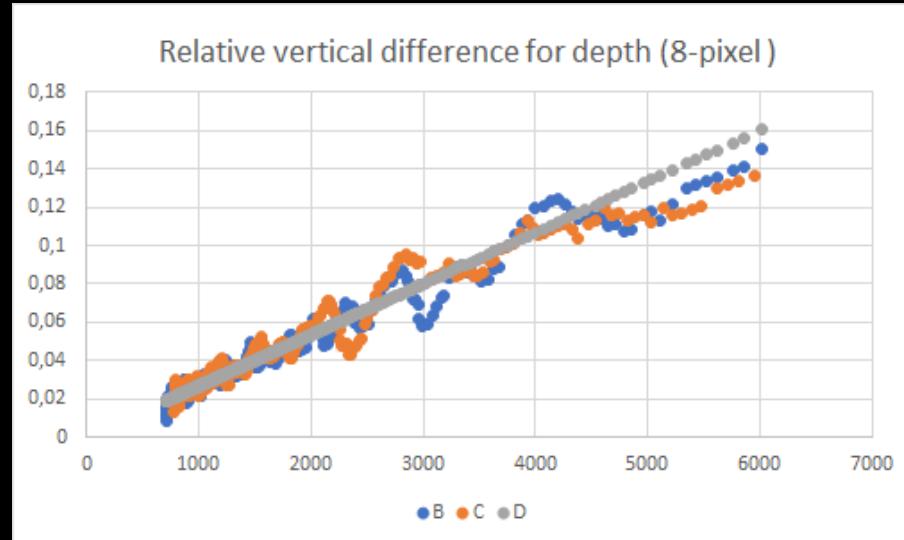
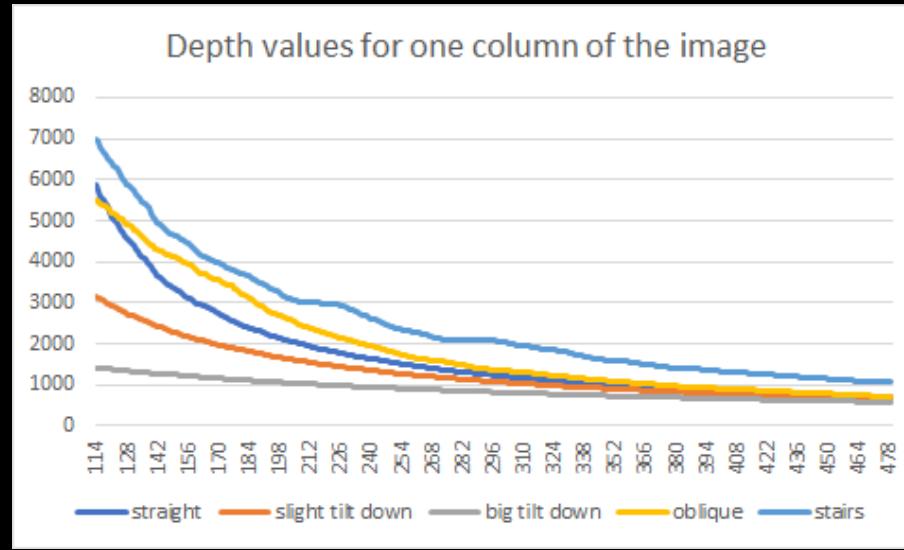
DEPTH CAMERA: Intel RealSense D435



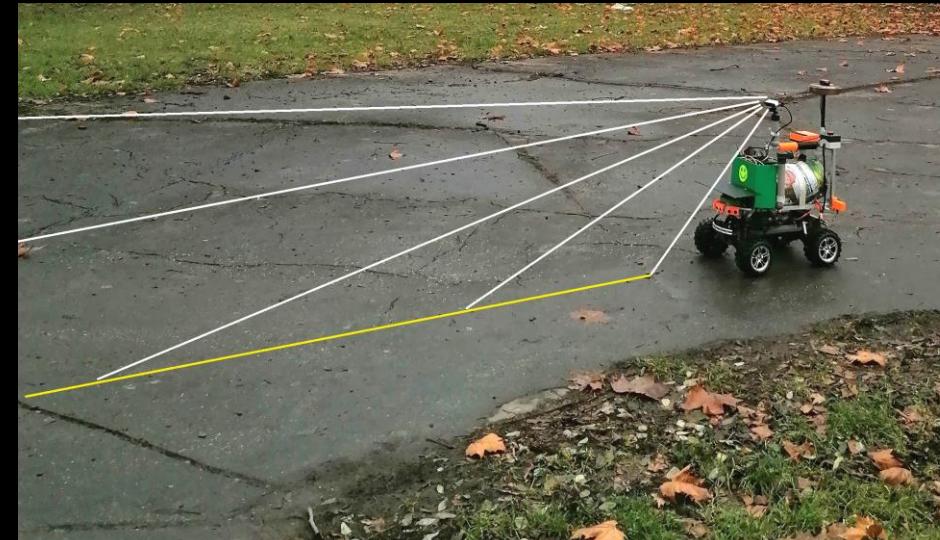
- Intel RealSense D435 features
 - Color Camera Horizontal FOV: 69° , 1920x1080
 - Depth HD Horizontal FOV: 87° , 1280x720
 - IR Projector - to improve depth accuracy in scenes with low texture
- We process images in these resolutions:
 - RGB: 640x480
 - Depth: 848x480
- Other depth camera alternatives:
 - Stereolab ZED Mini, 400+ Eur, includes precise IMU for positional tracking (Smelý Zajko)



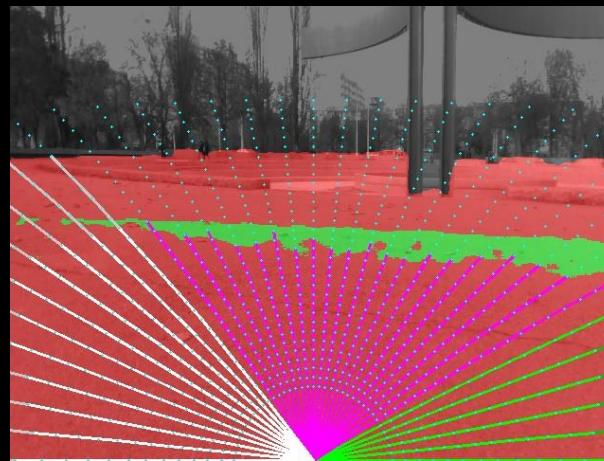
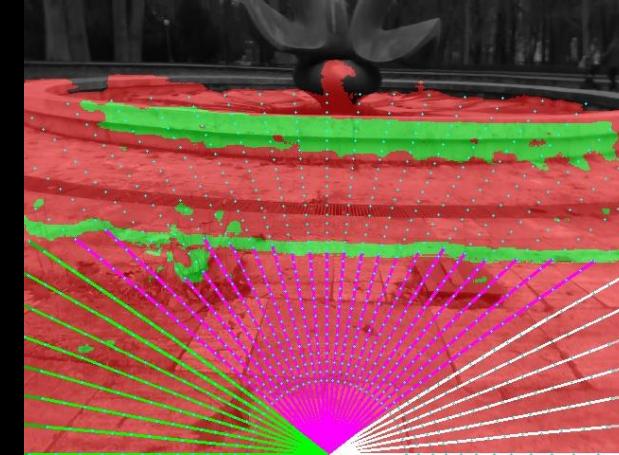
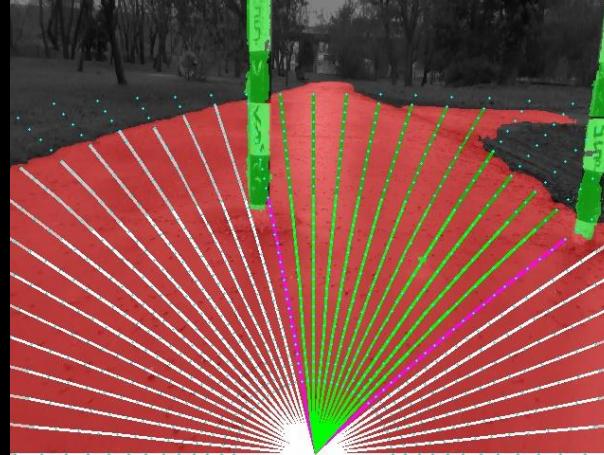
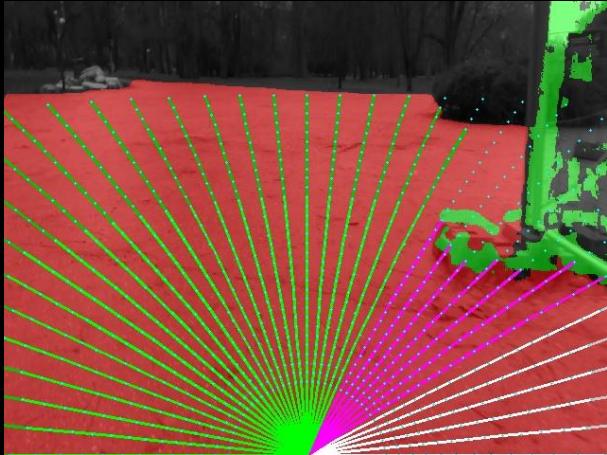
DEPTH IMAGE PROCESSING



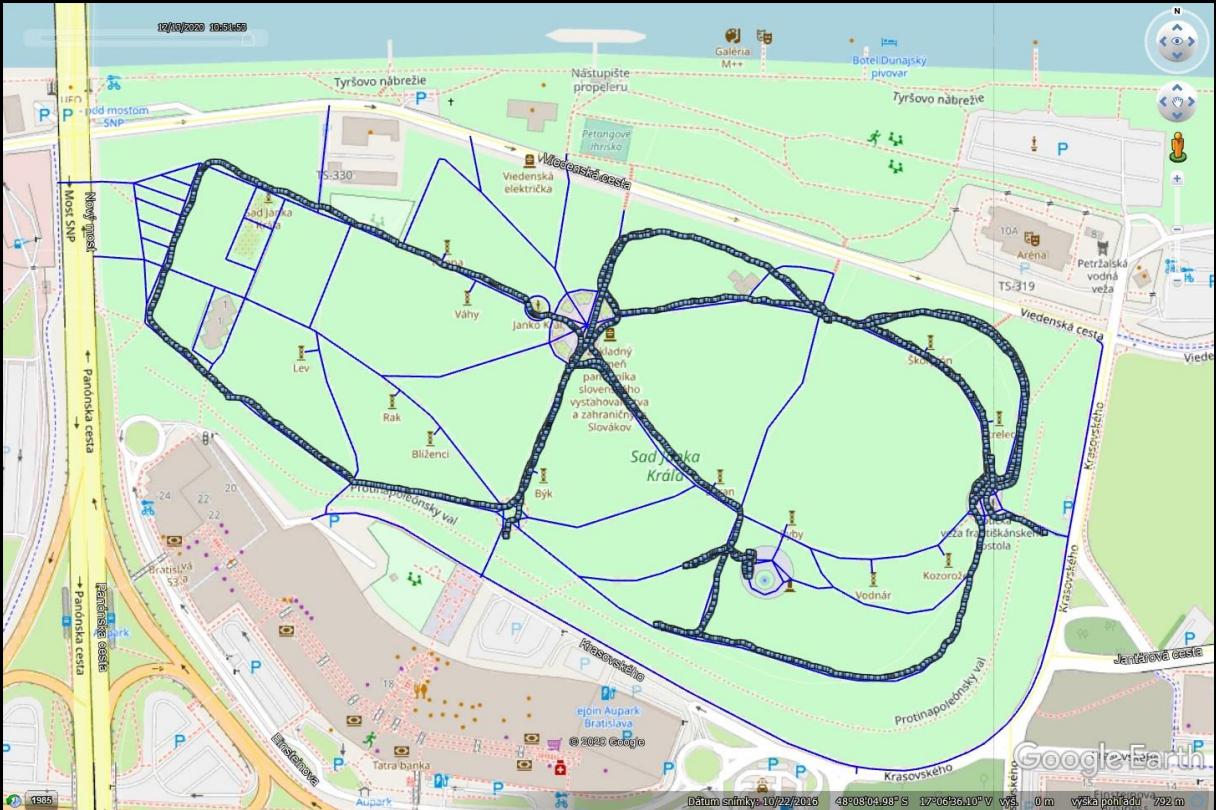
- Detecting obstacles and holes in the road
 - take two pixels: (x, y) and $(x, y+8)$
 - calculate the difference between the depth values of these two pixels
 - divide by the depth value of the second pixel
 - compare with min and max linear boundary
- Processing time (848x480): 45 ms / image



...IMAGE SEQUENCE #2

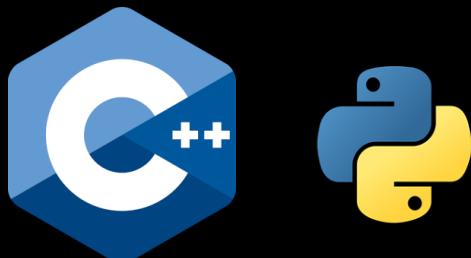
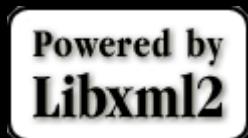
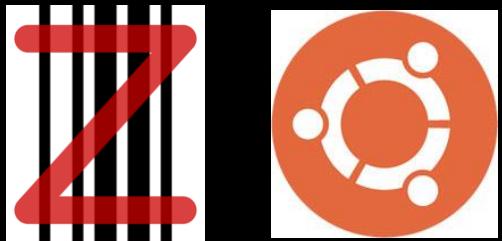


Robotour Marathon - 13.12.2020, 3.95km



- In 2020 we finally implemented
 - wrong-way behavior
 - full-stop (based on vision)
 - Problems
 - wrong turns at crossroads
 - sun and water are causing image processing issues
 - roads made of concrete panels
 - grass paver system
 - High-capacity batteries are needed to drive in winter
 - we also have a tablet in case the laptop's battery runs out

SOFTWARE



- Operating system: Ubuntu 18.04 (Linux4Tegra)
- Source codes: C++, 707kB
 - 2019: 664kB, 2018: 430kB,
 - 2017: 340kB, 2016: 180kB
- NN: Tensorflow, Keras, Python
- Libraries:
 - OpenCV (vision), GeographicLib (Geo),
 - Zbar (QR-Codes), Libxml2 (.osm),
 - log4cxx (logging)
- Main application + 8x pthreads
 - 4x sensors (Camera, Lidar, GPS , Compass)
 - image capturing + vision processing
 - output: image saving (1GB of data/ round)
 - control board (Compass)

SOURCE CODES



- Sources codes are available at GitHub as public project **Istro RT**:

<https://github.com/lnx-git/istro-rt>

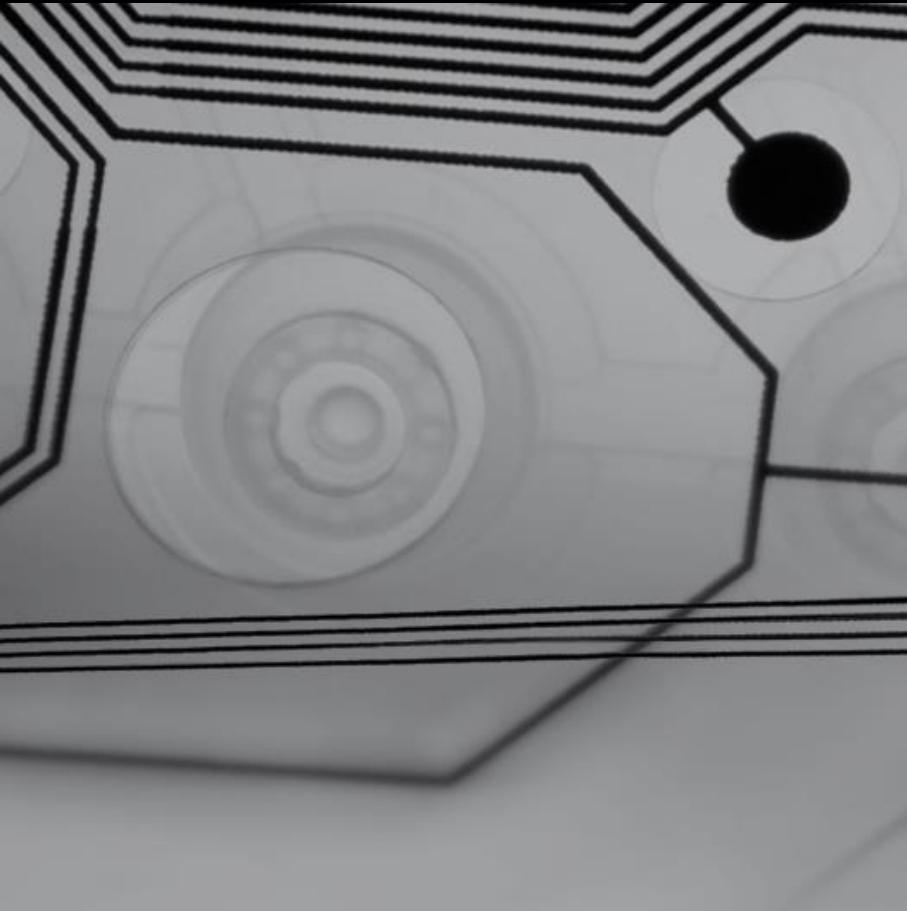
REFERENCES

- [1] Adrián Matejov, Efficient Convolutional Neural Networks Recognizing Driveable Trails, Master's Thesis 2020
 - <https://github.com/Adman/master-thesis/blob/master/efficient-cnns-recognizing-driveable-trails.pdf>
- [2] Alasdair Allan: Benchmarking Edge Computing: Comparing Google, Intel, and NVIDIA accelerator hardware
 - <https://medium.com/@aallan/benchmarking-edge-computing-ce3f13942245>
- [3] Matt Cooper: When Conventional Wisdom Fails: Revisiting Data Augmentation for Self-Driving Cars
 - <https://towardsdatascience.com/when-conventional-wisdom-fails-revisiting-data-augmentation-for-self-driving-cars-4831998c5509>

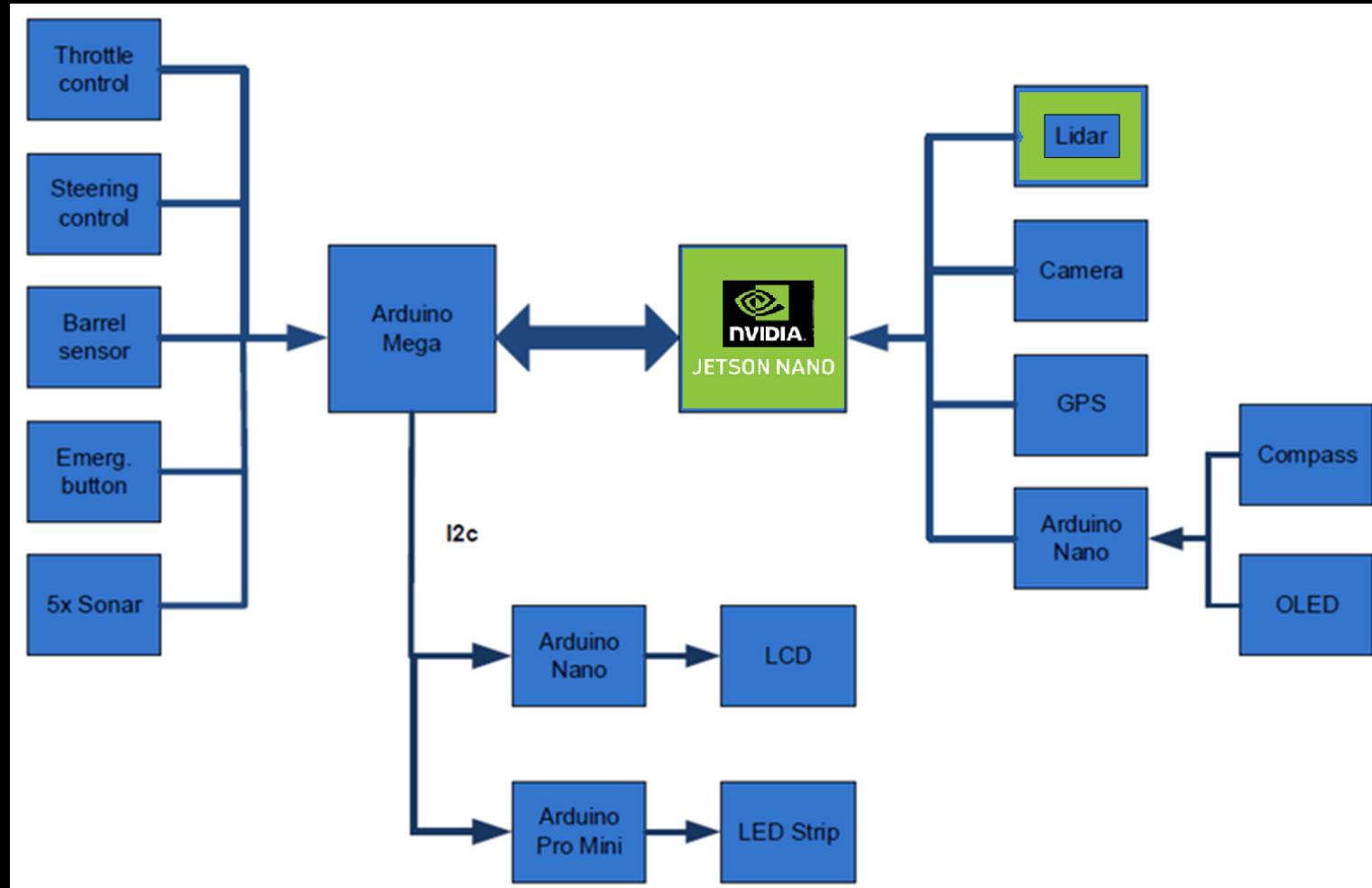
THANK YOU



GENERAL SLIDES



HARDWARE DESIGN

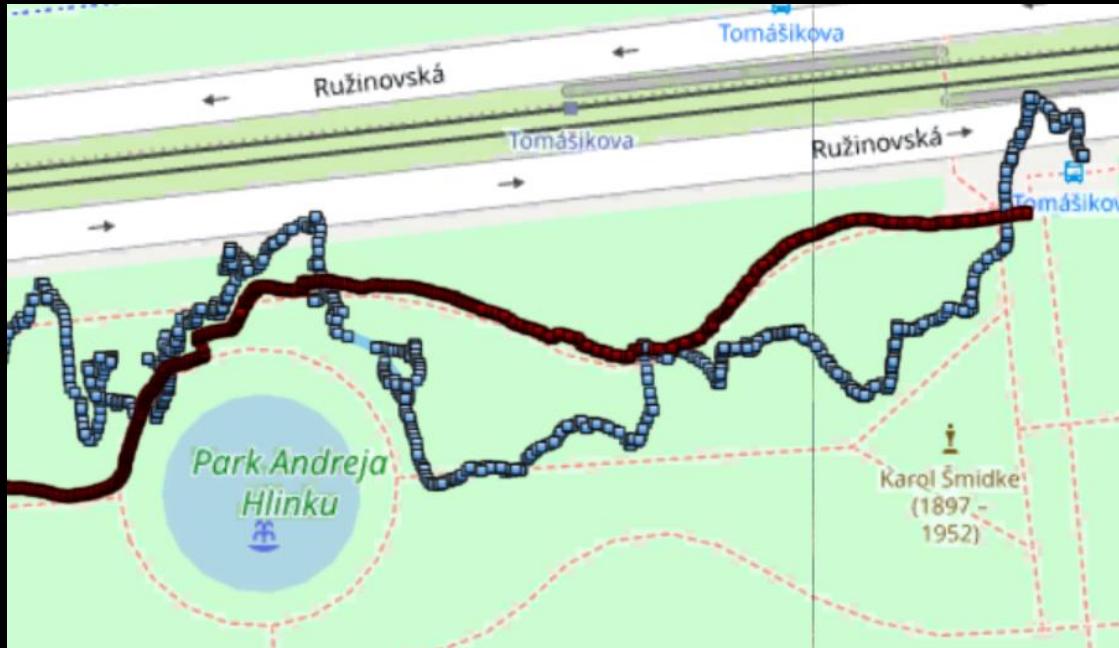


Jetson Nano vs Odroid-XU4

	Raspberry Pi3	Odroid-XU4	Jetson Nano
CPU	ARM Cortex-A53	Samsung Exynos5422 Cortex	ARM Cortex-A57
Clock	1.2 GHz	2 GHz	1,43 Ghz
Cores	4x	8x	4x
RAM	1GB LPDDR2	2GB LPDDR3	4GB LPDDR4
Flash	microSD	eMMC5.0 HS400	microSDXC Class 10 UHS-I
Ethernet	10/100 Mbit	1 Gigabit	1 Gigabit
USB	4x USB 2.0	2x USB 3.0 1x USB 2.0	4x USB 3.0

	R-Pi3	O-XU4	J-Nano
Image processing	167,3 ms	39,4 ms	27,3 ms
JPG/PNG writing	55 ms	17,7 ms	8,1 ms
Processing lag	2 sec	100 ms	0 ms (ramdisk)

GPS GROUND PLANE



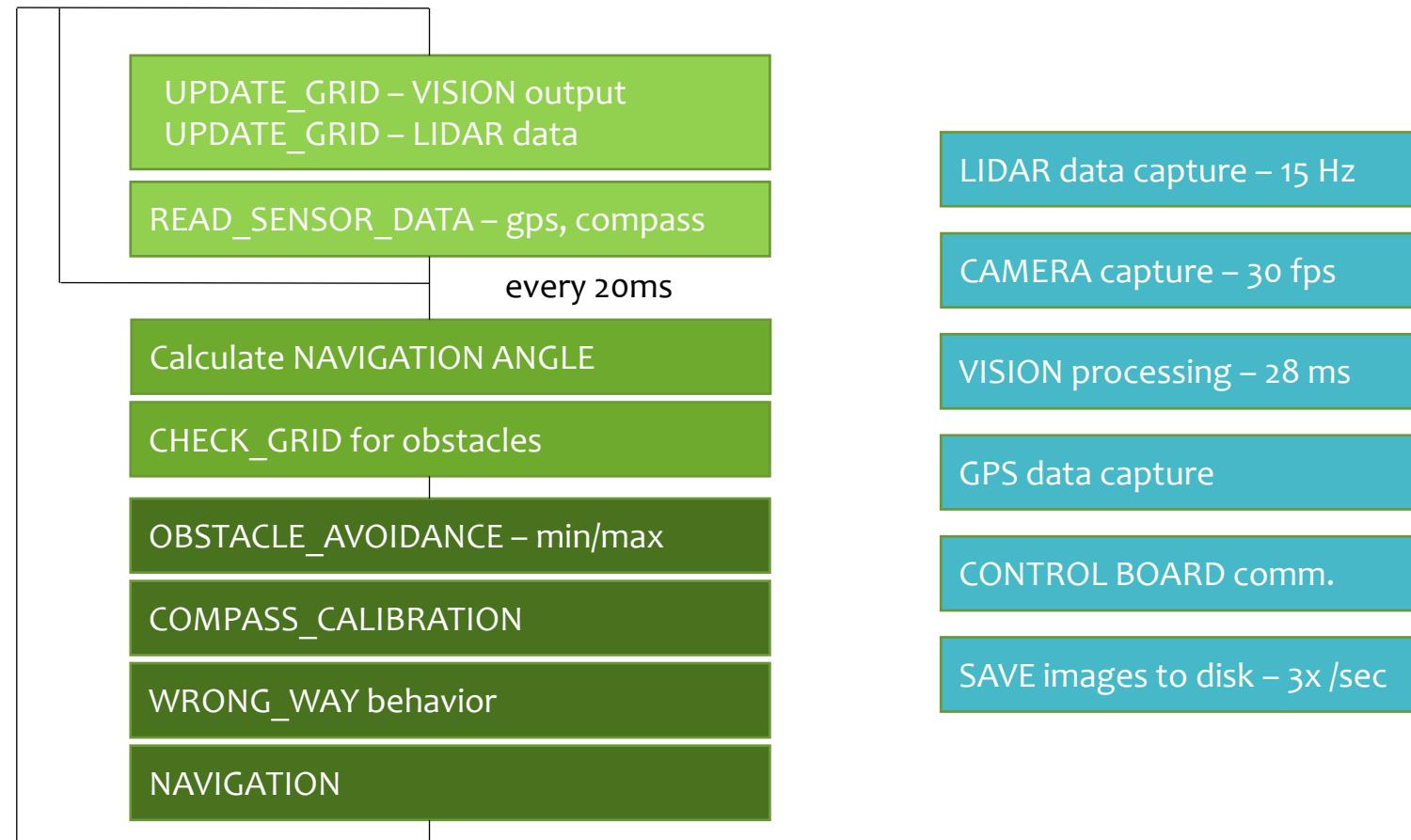
- U-Blox GPS Antenna documentation
 - Patch antennas - flat surface is ideal
 - can show very high gain, if mounted **on large ground plane (70x70mm)**
- USB 3.0 impact on GPS
 - Intel paper: USB 3.0* Radio Frequency Interference Impact on 2.4 GHz Wireless Devices
- We used simple shield for GPS
- Results: **great improvement (3m accuracy)**

170FOV CAMERA

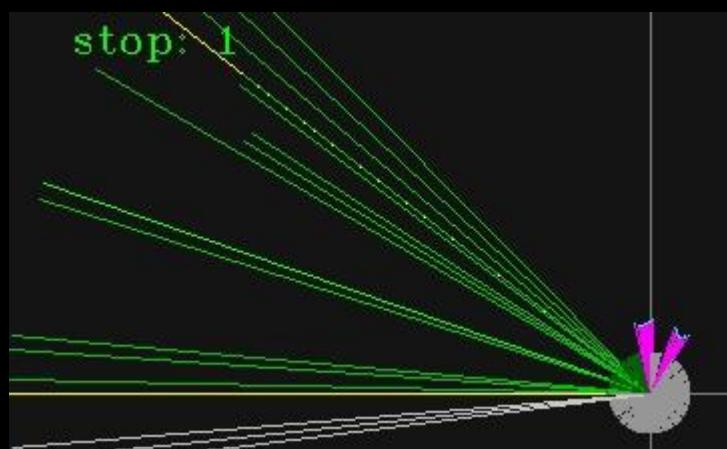
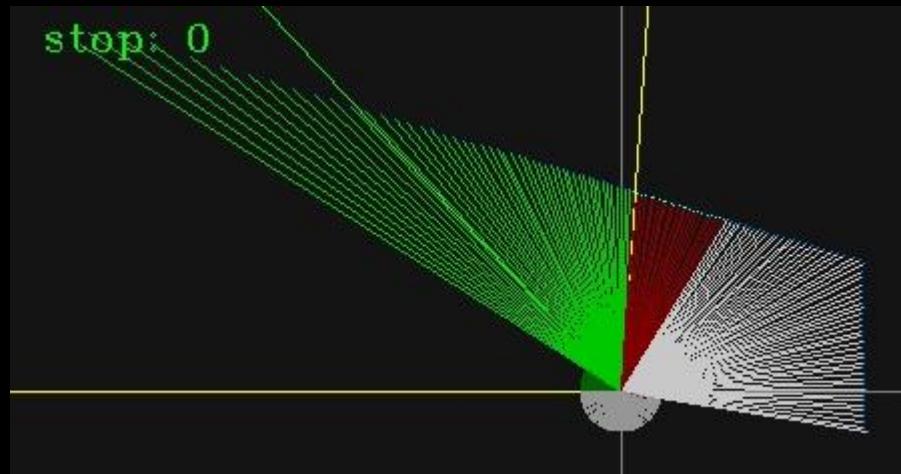


- **oCam : 5MP USB 3.0 Camera**
 - OmniVision OV5640 CMOS image sensor
 - Original lens Field Of View: 65 Degree
- Exchangeable Standard M12 Lens
 - Separate: 170 Degree Wide Angle
 - (standard accessory also for GoPro cameras)
- we 3d-printed an adjustable camera holder (fixed by screws)
- we broke the USB connector during the first test drive

SOFTWARE DESIGN – PROCESSING

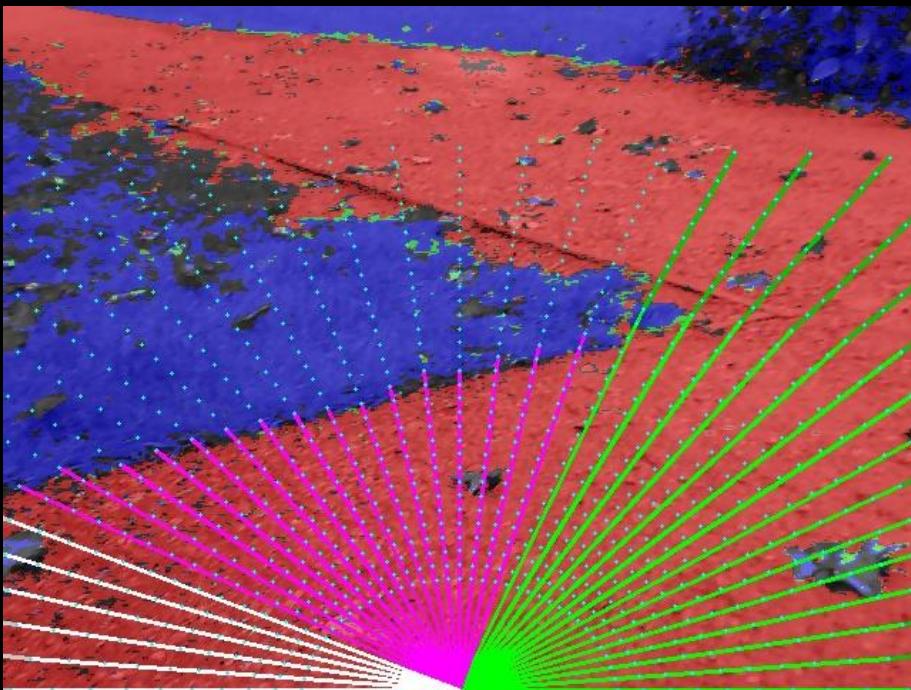


LIDAR – obstacle detection



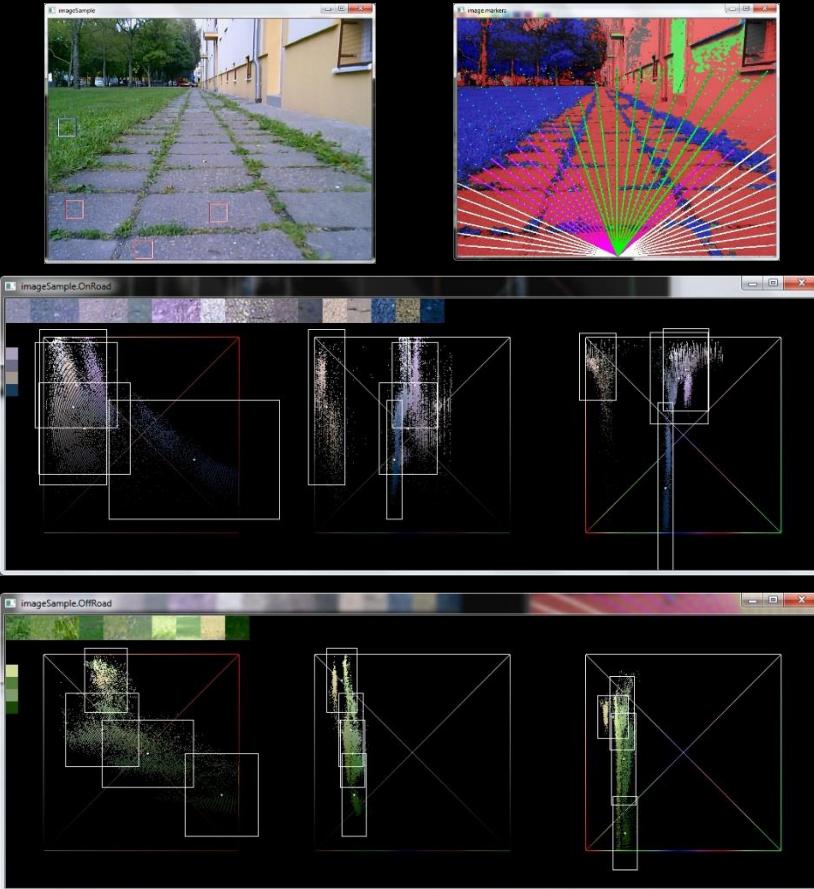
- Obstacle detection condition (red):
 - If distance is < 100 cm
 - Filtering: distance < 1cm (grey)
- Stop condition (pink):
 - Check angle: -45 to +45 degrees
 - If distance is < 50 cm at 3 diff. degs
 - Sonars were also used (rain issue)
- Obstacle avoidance (green/white)
 - Find OK intervals of > 20 degrees
 - Choose the closest to going straight

VISION – approach

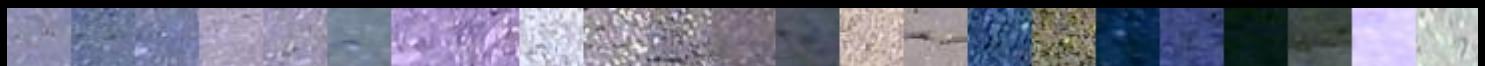
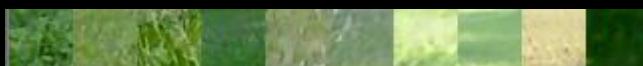


- Our approach: **lidar-like local map**
 - For any seen angle is obstacle closer than 1 meter?
 - 1 meter or to the image border
- Algorithm:
 - Pixel color classification
 - Evaluate grid points
 - Calculate distance to obstacle
 - Find OK intervals – same like LIDAR

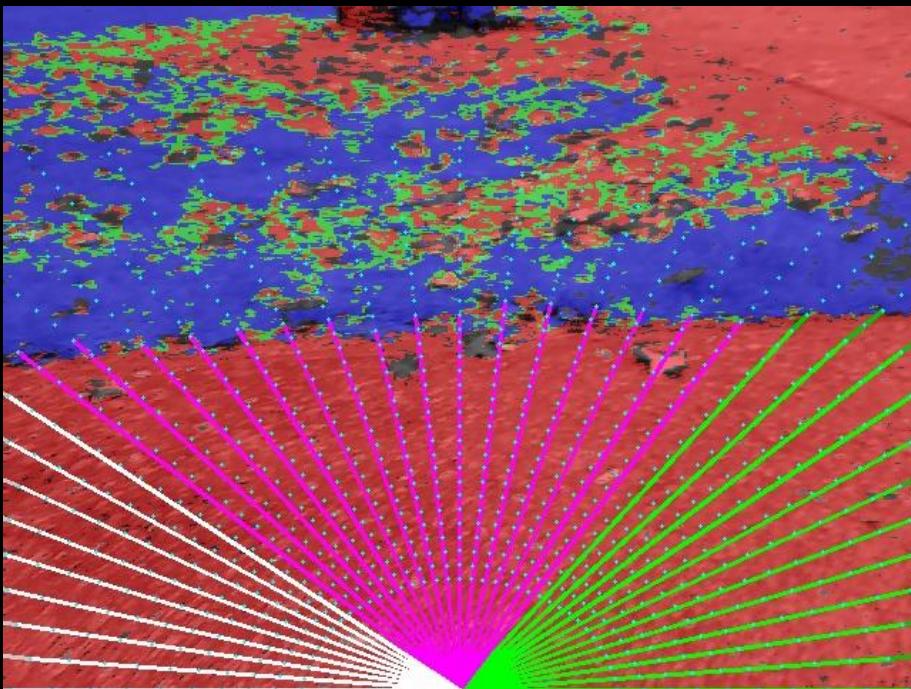
VISION - Pixel color classification



- Approach:
 - Choose sample pixel blocks (32×32) from training images
 - Calculate 4 clusters centers in color space (OpenCV kmeans)
 - Calculate cluster radius (histogram based)
 - Repeat for 2 classifiers : road and off-road (grass)
- HSV color space + Euclidian distance
- tool to evaluate images and to select sample blocks



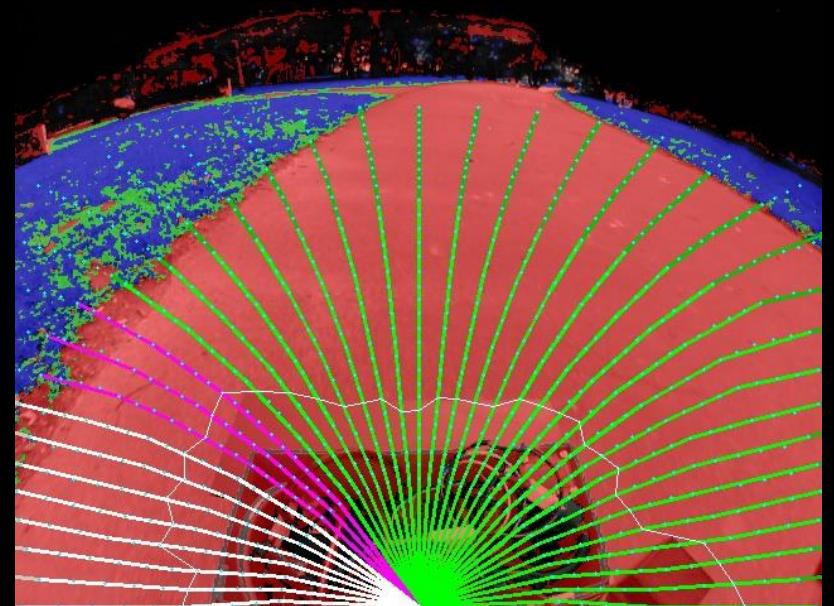
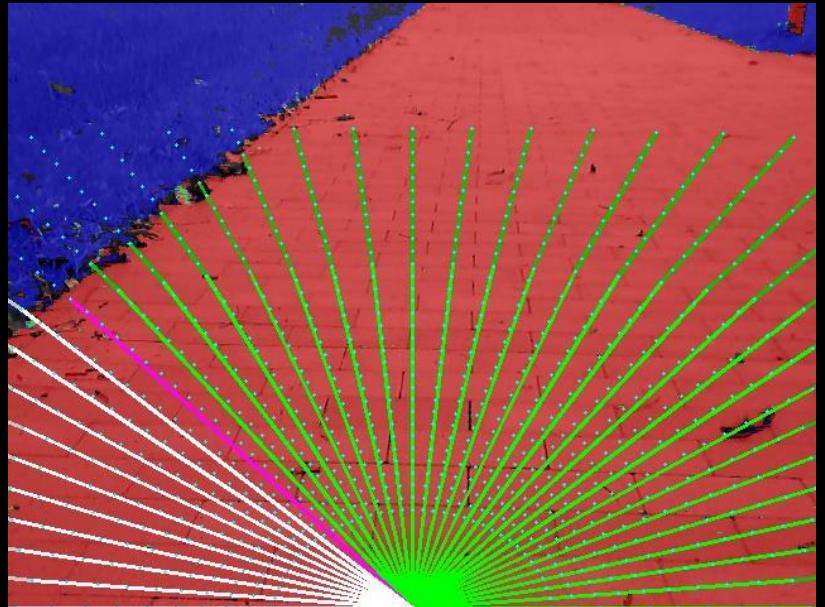
VISION - Algorithm



- Pixel color classification - 4 results:
 - Road (red)
 - Off-road (blue)
 - Both (green)
 - None (grey)
- Evaluate grid points
 - Cca 1000 points in 37 lines (5 deg)
 - Evaluating nearby pixels (80x80)
 - Majority of “Road” pixels is checked
- Calculate distance to obstacle
- Find OK intervals + merge with LIDAR

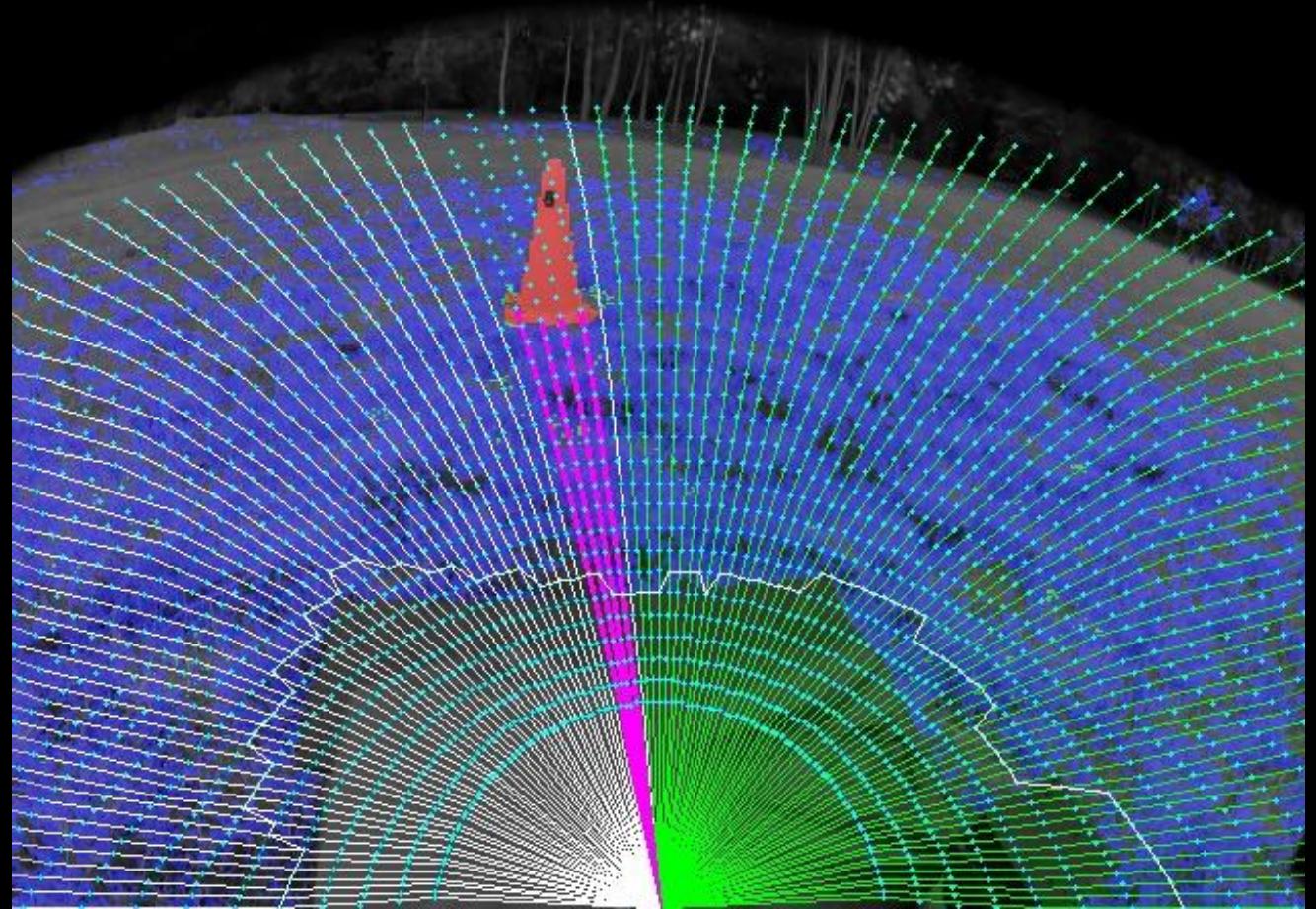
FISHEYE IMAGE PROCESSING

- **image transformation**
 - correction of mapping between XY points and local map coordinates – curved lines
 - OpenCV undistort() was not used (because of slow performance)
- **front side of the robot on every image**
 - was fixed by SW masking
 - presents an issue for training a neural network
- **sky was “masked” using a black tape**
 - for avoiding white ballancing camera issues



VISION - ROBOORIENTEERING

- Vision algorithm was modified to detect orange cones

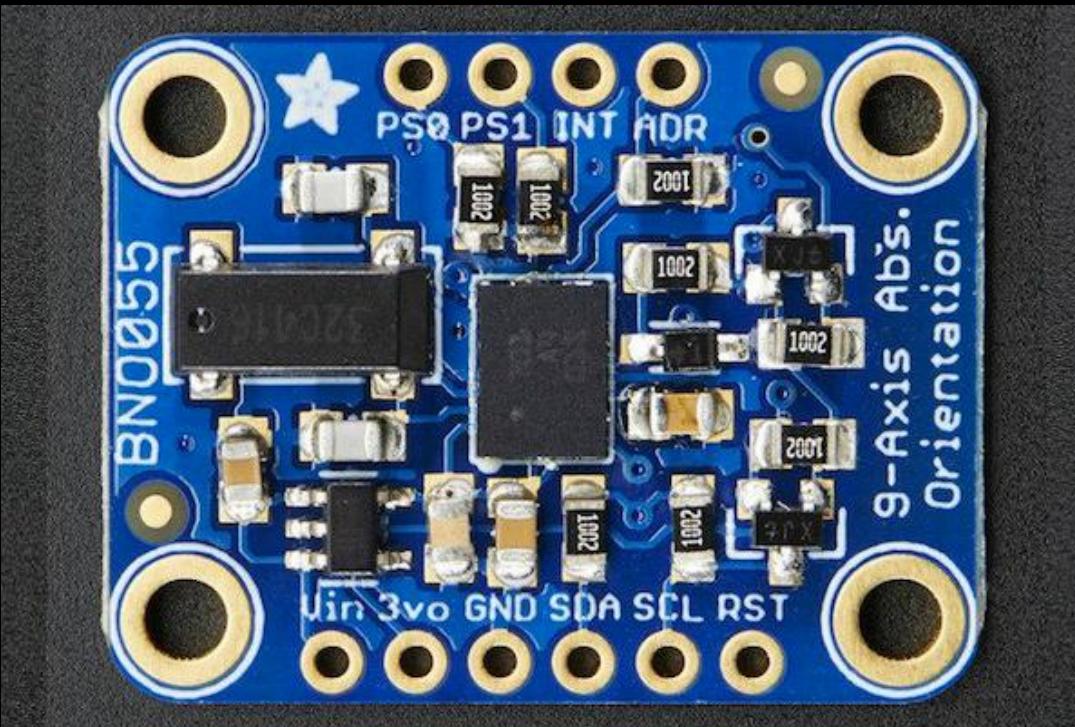


NAVIGATION – ROUTE PLANNING



- OpenStreetMap data export
 - filter segments: footway, track with <grade3
- **Dijkstra's Shortest Path Algorithm**
 - 418 nodes, 504 segments
- Performance: < 2ms
- Visualisation: kml export, cpp export
- Navigation: keep azimuth towards a point that is 10m along planned route

COMPASS ISSUES



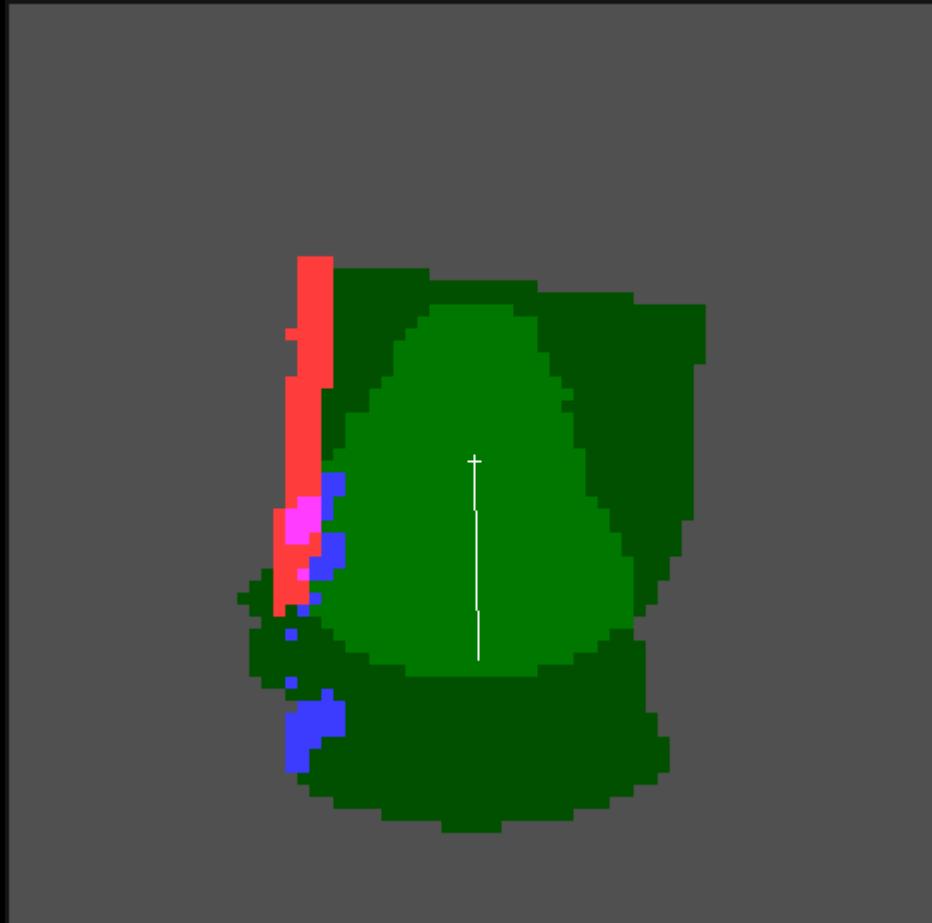
- Compass vs GPS calibration:
 - interval of 7 seconds - robot is moving straight
 - gps and compass azimuths to be fixed
 - could be performed every 30 seconds – 3 minutes
- Issues:
 - after Round #1 very inaccurate results – delta values between 45° and 90 °
 - robot is sometimes slightly left turning
 - local changes during the day (bridge)
- for testing in Bratislava and also for competition we used fixed value 60 °

QR CODES

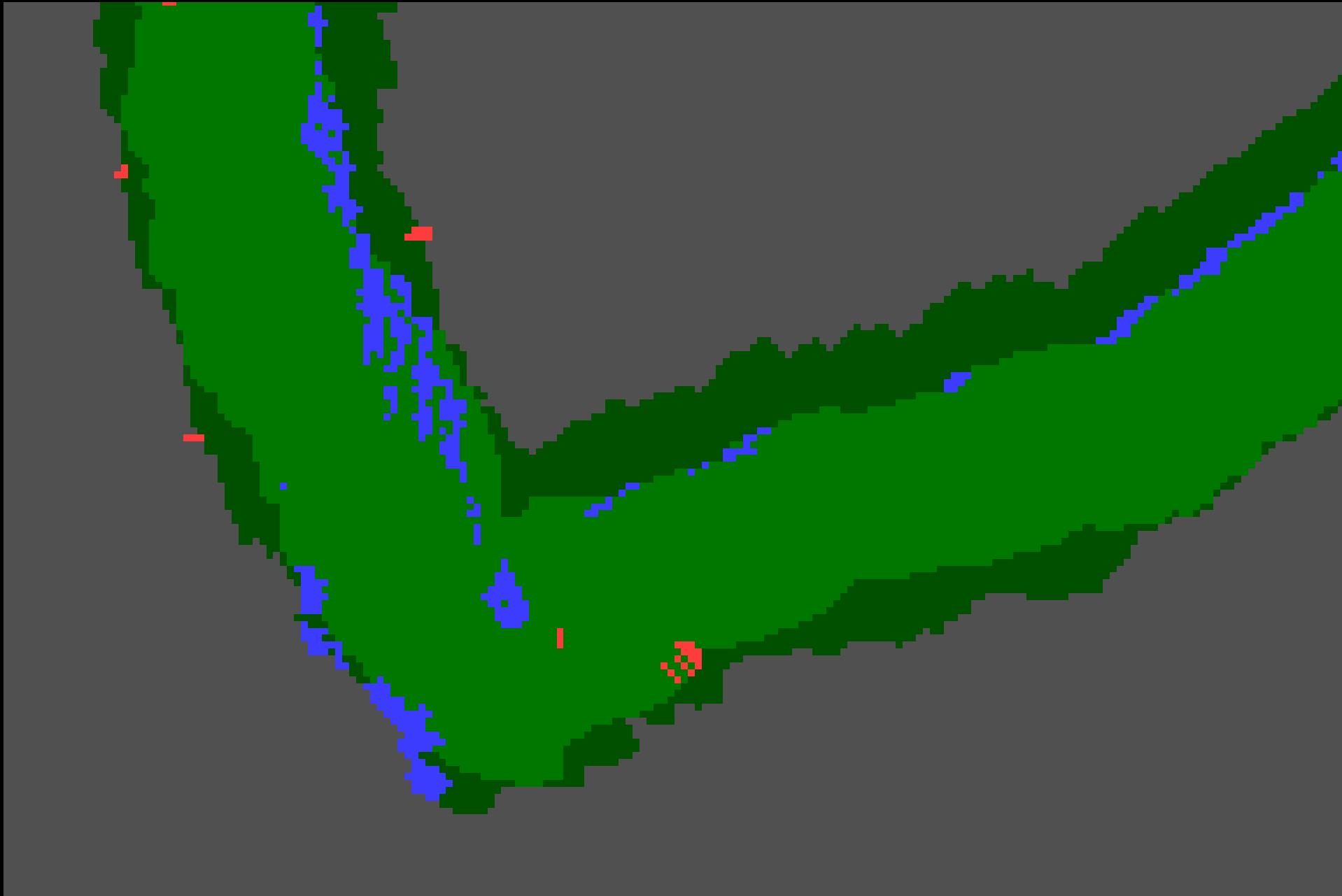


- **ZBar bar code reader**
 - open source software suite
 - supports: EAN-13/UPC-A, UPC-E, EAN-8, Code 128, Code 39, Interleaved 2 of 5 and QR Code
- Performance impact:
 - one execution: 50-200ms
 - our target 30-50ms per frame
- Solution: images are scanned for QR codes only when waiting for navigation coordinates

WORLD MAP - BUILDING LOCAL GRID



- Local grid map
 - to store polar information from lidar and vision
 - 1 cell: 10 x 10 cm, 1 byte per cell, array[2000][2000]
 - always overwriting with new data - no heatmap
- Local position taken from GPS + odometry
 - wheel encoders provide speed information
- Colors used for visualization
 - Blue – grass (not-a-road) detected
 - Red – lidar obstacle
 - Green - no obstacle (light green = both sensors)



VISUALISATION

- Visualization in web browser
 - works on notebook/tablet/phone
- Messages from log files
 - last set of lines matching selected substrings
 - Info: robot display, gps, processing, calibration
- Log parser is exporting interesting data do .json file
- Web page performs Ajax JSON requests every 1 sec
 - Images are only downloaded on demand (checkbox)

camera vision lidar wmgrid navmap [reload](#)

```
2018-09-08 05:29:07,005 INFO istro::process_thread(): process_angle("MIN MAX"): navp_azimuth=999999.00, process_yaw=166.52, process_angle_min=0, process_angle_max=91, process_angle=45, process_dir=90, yaw_src=1

2018-09-08 05:29:06,646 DEBUG istro::gps_writeData(): fix=1, latitude=48.156538, longitude=17.156745, latitude_raw=48.156538, longitude_raw=17.156745, speed=0.330, course=270.00, gps_x=-189.30, gps_y=-53.63, ref=1, navp_dist=-1.000, navp_azimuth=999999.00, navp_dist_raw=-1.000, navp_azimuth_raw=999999.00, navp_maxdist=-1.000, navp_mindist=-1.000, navp_loadarea=1, navp_idx=-1, navp_latitude=999999.000000, navp_longitude=999999.000000, navp_latitude_raw=999999.000000, navp_longitude_raw=999999.000000, lastp_dist=0.000, lastp_azimuth=0.00, nmap_flags=0

2018-09-08 05:29:07,026 DEBUG istro::process.readData(): process_change=52, gps_speed=0.330, gps_course=270.00, lastp_dist=-1.000, lastp_azimuth=0.00, ctrlb_ircv500=12.39, ctrlb_angle=96, ctrlb_velocity=91, ctrlb_loadd=1, euler_x=166.52, ahrs_yaw=999999.00, navp_dist=-1.000, navp_azimuth=999999.00, navp_maxdist=-1.000, navp_loadarea=1, navp_idx=-1, gps_ref=1, gps_x=-189.30, gps_y=-53.63

2018-09-08 05:28:39,831 INFO istro::calib_process(): msg="calibration interrupted (obstacle)!", calib.ok=0, process_angle_min=0, process_angle_max=92

2018-09-08 05:28:59,638 INFO istro::gps_thread(): msg="navigation point passed!", pos=4, name="*2", navp_dist=0.000, navp_mindist=19.756

2018-09-08 05:28:59,638 INFO navig::navigation_next_point(): msg="point not found!", pos=4

2018-09-08 05:29:07,026 TRACE istro::loadarea_process(): msg="unloading area - waiting!", gps_navp_idx=-1, gps_navp_azimuth=999999.00, process_state=4, gps_navp_loadd=1, ctrlb_loadd=1, navp_loadarea=1, ctrlb_ircv500=12.39, ctrlb_angle=96, ctrlb_velocity=91, ctrlb_loadd=1, euler_x=166.52, ahrs_yaw=999999.00, navp_dist=-1.000, navp_azimuth=999999.00, navp_maxdist=-1.000, navp_loadarea=1, navp_idx=-1, gps_ref=1, gps_x=-189.30, gps_y=-53.63

2018-09-08 05:29:06,591 INFO ControlBoard::write(): data="DAF:S0v343 A277 MMAX"
```