SLOVAK UNIVERSITY OF TECHNOLOGY IN BRATISLAVA
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Application of deterministic Ethernet for distributed embedded systems

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Content

1. INTRODUCTION

Problem of classic ethernet network is delivery based on „best efford“. This means that there is no guaranty of packet delivery (for example during network congestion). Deterministic ethernet is solution for this problem. Deterministic ethernet has been developed by TTTech. This technology can guarantee packet delivery during network congestion. That is why deterministic ethernet is widely used in real time application like automotive industry, space industry and others.

The main purpose of this project is to use deterministic ethernet in autonomous vehicle. The vehicle should be able to avoid obstacles on the road, navigate, recongize signs. This document aims to show reader basic information of our work. It consists of several sections like analysis, solution design, implementation and experiment.

This project was developed in an iterative and incremental agile software development framework called Scrum. It means that every member of team has their tasks to do and also reports to write.

1.1 Winter semester goals

Winter semester goals can be divided in the following points:

- assignment specification and application selection
- choice of software tools for communication, code storage and task management
- component analysis
- order of components
- vehicle construction
- communication design
- basic communication between devices

Assignment specification and application selection

Our team project was a big deal that it was not directly specified. For us it meant that we had to invent our own application. It was the first and main goal of the first weeks of the semester.

Choice of software tools

The goal of the selection of software tools was to find the tools that will help us in developing our product. Tools were related to communication, code sharing and task management.

Component analysis

The goal of the analysis was to analyze the components from which the vehicle will be constructed. It is also important for compatibility in order to avoid the scenario that the two components cannot communicate with each other.

Order of components

The output from the analysis of components were devices that we have been chosen for vehicle construction. Since we cooperate with Austrian company TTTech all of the purchases has to be done via this company. Buying process begins with provided list of components and prices for company approval. If the list is approved, then the components are ordered by company. If the list it's not approved, we have to make deeper analysis and suggest new components. The whole process is under the direction and control of our external supervisor. This process takes a lot of time and it was our main slow factor.

Car construction

Based on the purchase of components, the objective is to have the physical vehicle to the end of the winter semester.

Communication design

Our autonomous car will communicate through local network. From that reason, solution requires protocol, which will enable communication. The goal of the communication design is to implement new protocol, which makes communication among end devices possible.

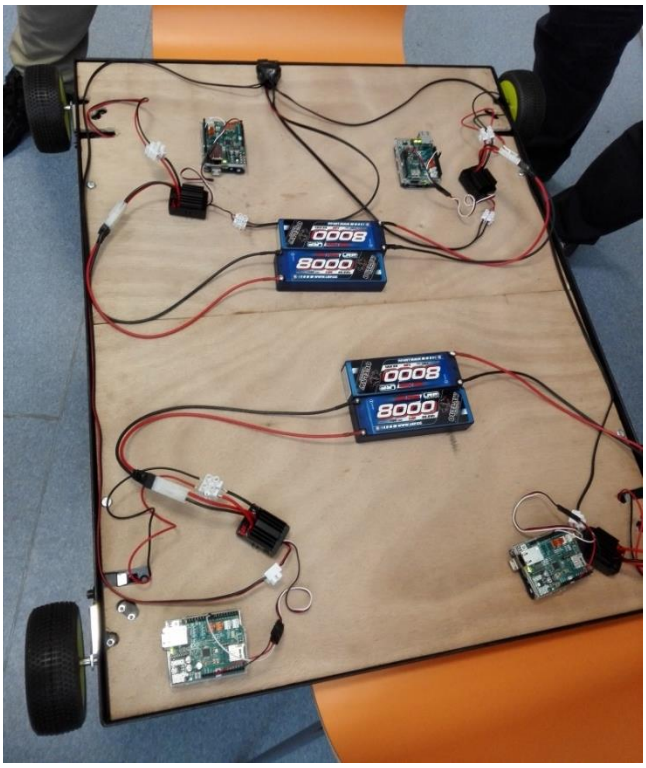
Basic communication between devices

One of the milestones of the winter semester is to create basic communication between devices on the local network of autonomous vehicle. This means that the objective is to send information from one device to another and vice versa.

1.2 General view of project

1.2.1 Vehicle construction

We have constructed our vehicle from ordered parts and tested its movement control. We will continue building after all ordered parts will arrive. Current state of our vehicle can be seen on picture below. Design can be found in chapters 3.1 and 3.2 and car wiring in chapter 4.4. Experiments from movement testing are in chapters 5.1 and 5.2.



Constructed vehicle

1.2.2 Software prototypes

We have created software prototypes for communication with devices, processing data from laser and GPS and for central control unit. Principles of these prototypes can be found in chapters 3.4, 3.5, 3.6, 3.7, 4.2, 4.3 and 4.5.

2. ANALYSIS

This section contains analysis of components which some of them are part of autonomous car. Components are divided into sensors, batteries, car platforms, boards, cameras.

2.1 SENSORS – GPS

GPS receivers use a constellation of satellites and ground stations to compute position and time almost anywhere on earth. At any given time, there are at least 24 active satellites orbiting over 12,000 miles above earth. The positions of the satellites are constructed in a way that the sky above your location will always contain at most 12 satellites. The primary purpose of the 12 visible satellites is to transmit information back to earth over radio frequency (ranging from 1.1 to 1.5 GHz). With this information and some math, a ground based receiver or GPS module can calculate its position and time.

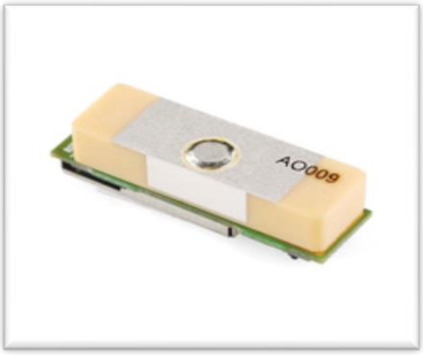
The data sent down to earth from each satellite contains a few different pieces of information that allows your GPS receiver to accurately calculate its position and time. An important piece of equipment on each GPS satellite is an extremely accurate atomic clock. The time on the atomic clock is sent down to earth along with the satellite's orbital position and arrival times at different points in the sky. In other words, the GPS module receives a timestamp from each of the visible satellites, along with data on where in the sky each one is located (among other pieces of data). From this information, the GPS receiver now knows the distance to each satellite in view. If the GPS receiver's antenna can see at least 4 satellites, it can accurately calculate its position and time**.** This is also called a lock or a fix.

All of GPS modules can be compared according to parameters. Here are some of them.

Accuracy - GPS accuracy varies but you can usually find out where you are, anywhere in the world, within 30 seconds, down to +/– 5 meters. The +/– is there because accuracy can vary between modules, time of day, clarity of reception, etc. Overall, to get the best accuracy from GPS, it must be in clear view of the sky and moving.

Antenna - GPS module is receiving signals from satellites about 12,000 miles away, so for the best performance, we need a clear path between the antenna and most of the sky. Weather, clouds, snow storms, shouldn't affect the signal, but things like trees, buildings, mountains, the roof, will all create unwanted interference and GPS accuracy will suffer.

There are many antenna choices, but these are some of the most common.

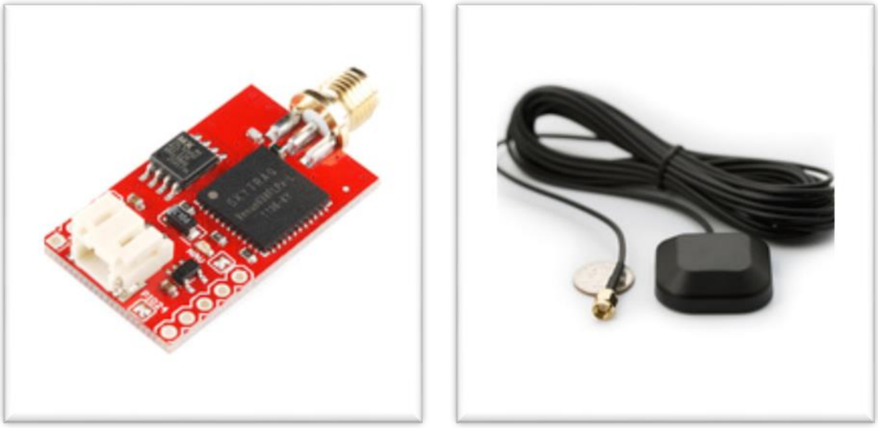


Ceramic patch antenna.

This antenna is low profile, inexpensive, and compact, but it has lower reception compared to other types of antennas. This antenna needs to face upwards with a clear view of the sky to get good a good signal, so the gain of the antenna is greatest when facing up.

Helical antenna

This antenna can take up more room than the ceramic patch, but the shape of the antenna allows for a better signal in any orientation, at the expense of slightly lower gain in any one specific orientation.



Module with a SMA antenna attachment

The SMA attachment gives the ability to mount antenna in a different location than our main circuit. This can be beneficial if main system is not in good view of the sky. For example, inside of a building or in a car which can be our case.

Baud Rate - GPS receivers send serial data out of a transmit pin (TX) at a specific bit rate. The most common is 9600bps for 1Hz receivers but 57600bps is becoming more common.

Channels - The number of channels that the GPS module runs will affect time to first fix (TTFF). Since the module doesn't know which satellites are in view, the more frequencies/channels it can check at once, the faster a fix will be found. After the module gets a lock or fix, some modules will shut down the extra blocks of channels to save power.

Chipset - The GPS chipset is responsible for doing everything from performing calculations, to providing the analog circuitry for the antenna, to power control, to the user interface. The chipset is independent of the antenna type, therefore you can have a range of different antennas for GPS modules with specific chipsets. Common chipsets are ublox, SiRF, and SkyTraq and all contain very powerful processors that allow for fast acquisitions times and high reliability. The differences between chipsets usually falls on a balance between power consumption, acquisition times, and accessibility of hardware.

Gain - The gain is the efficiency of the antenna in any given orientation. This applies to both transmitting antennas and receiving antennas.

Lock or Fix - When a GPS receiver has a lock or fix, there are at least 4 satellites in good view and you can get accurate position and time.

NMEA - This is a common data format that most GPS modules use. NMEA data is displayed in sentences and sent out of the GPS modules serial transmit (TX) pin. The NMEA sentences contain all of the useful data, (position, time, etc.).

Power - On average, a common GPS module, with a lock, draws around 30mA at 3.3V.

PPS - Pulse per second. This is an output pin on some GPS modules.

Start-up Times (Hot, Warm, and Cold) - Some GPS modules have a super-capacitor or battery backup to save previous satellite data in volatile memory after a power down. This helps decrease the TTFF on subsequent power-ups. Also, a faster start time translates into less overall power draw.

- Cold Start - If you power down the module for a long period of time and the backup cap dissipates, the data is lost. On the next power up, the GPS will need to download new almanac and ephemeris data.
- Warm Start - Depending on how long your backup power lasts, you can have a warm start, which means some of the almanac and ephemeris data is preserved, but it might take a bit extra time to acquire a lock.
- Hot Start: A hot start means all of the satellites are up to date and are close to the same positions as they were in the previous power on state. With a hot start the GPS can immediately lock.

TTFF - Time to first fix. The time it takes, after power-on, to accurately compute your position and time using at least 4 satellites. If you are in a location with a bad view of the sky, the TTFF can be very long.

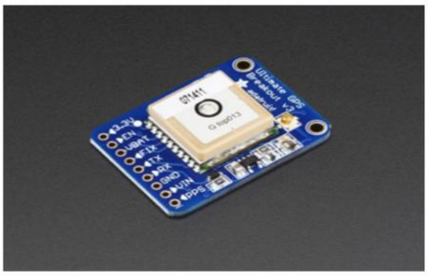
Update Rate - The update rate of a GPS module is how often it calculates and reports its position. The standard for most devices is 1Hz (once per second). UAVs and other fast vehicles may require increased update rates. 5 and even 10Hz update rates are becoming available in low cost modules.

2.1.1 GPS modules

We have been deciding mainly among two boards for Raspberry Pi. Adafruit ultimate GPS breakout and RasPiGNSS. The main decision factors were ease of installation, detailed documentation and existing projects on forums. After selecting Altera board a PMOD GPS Receiver (SKU: 410-237) was chosen.

2.1.1.1 Adafruit Ultimate GPS Breakout

This module has detailed step by step guide for Arduino and raspberry pi boards and that is the main reason we have chosen this GPS module. It offers very good specifications according to its price.



Adafruit Ultimate GPS Breakout

It supports also DGPPS, WAAS, EGNOS, jammer detection and reduction and multi-path detection and compensation. Output of this module is in standard NMEA format with 9600 baud rate.

Parameters	
Price	+/- 40 Euro
Weight	8.5g
Dimensions	25.5mm x 35mm x 6.5mm
Sattelites	22 tracking, 66 searching
Patch Antenna Size	15mm x 15mm x 4mm
Update rate:	1 to 10 Hz
Position Accuracy:	< 3 meters
Velocity Accuracy:	0.1 meters/s
Warm/cold start:	34 seconds
Acquisition sensitivity:	-145 dBm
Tracking sensitivity:	-165 dBm
Maximum Velocity:	515m/s
Vin range:	*3.0-5.5VDC*

2.1.1.2 RasPiGNSS

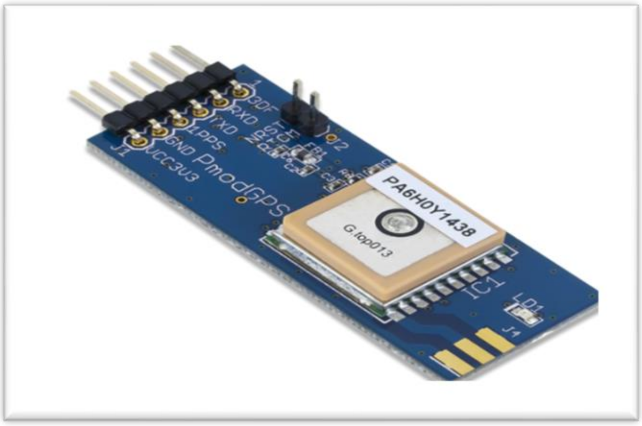
This module was tested for compatibility with raspberry pi 3 B and has updated installation guide according to it. For 170 euro, it is not very much better than the previous Adafruit ultimate GPS breakout.

RasPiGNSS

Parameters	
Price	+/- 170 Euro
Weight	22g
Channels	32
Patch Antenna Size	15mm x 15mm x 4mm
Update rate:	1 to 10 Hz
Position Accuracy:	< 2 meters
Velocity Accuracy:	0.05 meters/s
Warm/cold start:	25 seconds
Tracking sensitivity:	-160 dBm
Maximum Velocity:	500m/s
Maximum Acceleration	5G

2.1.1.3 PMOD GPS receiver

The Pmod GPS can provide satellite positioning accuracy to any embedded system. By communicating through UART with the GlobalTop FGPMMOPA6H GPS antenna, users may benefit from the 3 meters accuracy for any long term traveling. Due to an end of life notice on the Gms-u1LP antenna module, the PmodGPS will be using the FGPMMOPA6H module.



PMOD GPS receiver

Parameters	
Price	+/- 39.99 Euro
Weight	22g
Channels	66, 22 tracking
Patch Antenna Size	50mm x 20mm x 4mm
Update rate:	1 to 10 Hz
Position Accuracy:	< 3 meters
Velocity Accuracy:	0.1 meters/s
Warm/cold start:	33 / 35 seconds
Tracking sensitivity:	-165 dBm
Maximum Altitude	18 000 meters
Maximum Velocity:	515m/s
Maximum Acceleration	4G

2.1.1.4 Brief analysis of other modules


Gps add-on

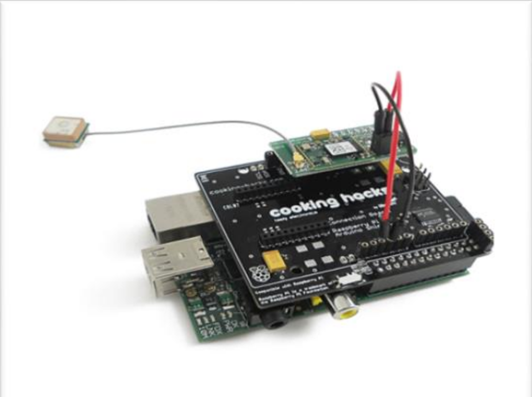
The 25.75€ add-on for Raspberry Pi B is based on the NEO-6 GPS module. With an input voltage of 3.3V and UART interface, the module returns information such as the current location and time. The add-on is also compatible with the Raspberry Pi Model B+.

GPS expansion board

Specially designed for Pi Model B+, the GPS board provides general information about the position and time. At a price of 47.00€, the board is based on the low power usage and high-performance positioning module called Ublox MAX-M8Q.

USB GPS Dongle

The easiest way to turn your fruit-named single board computer into a navigation device is to use a USB GPS dongle. At a price of 39.00€, the small piece of hardware supports Linux and ARM architecture. Also, it’s based on the high sensitive GPS chipset called SiRF Star III.



GPS shield

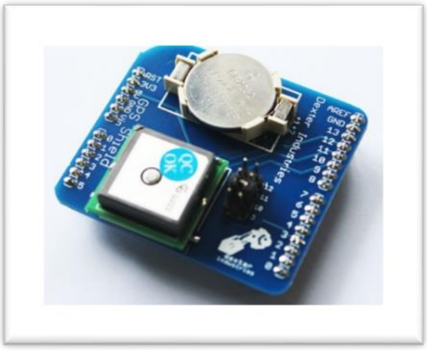
Using the standard NMEA protocol to provide information like speed, position and altitude, the GPS shield works great both inside and outside. It is available at a price of €82.00 and enables the data via serial port.

EM-506

The €35.00 GPS module is another receiver based on the SiRF StarIII chipset. Like the USB GPS dongle described above, the EM-506 provides the position very accurate even in urban canyon and dense foliage environment. The features include a position accuracy of 2.5m, and without any network assistance, it can predict for up to three days the satellite positions.

3G/GPRS shield

The 3G/GPRS shield is a device designed for Internet of Things applications. And because we are talking here about GPS data, the shield also provides the location and stay connected to the 3G network. The price is huge, about €149.00, and it’s compatible with Pi, Intel Galileo and Arduino boards.



Dexter Industries GPS

With an accurate position of 2.5 meters and a velocity of 0.1 m/sec, the Dexter Industries GPS is a good solution to build an all-in-one tracking application. The €39.00($45.00) shield can work on Raspberry Pi only with the Arduberry shield. The Arduberry shield is compatible with the Raspberry Pi and allows you to attach the receiver shield.

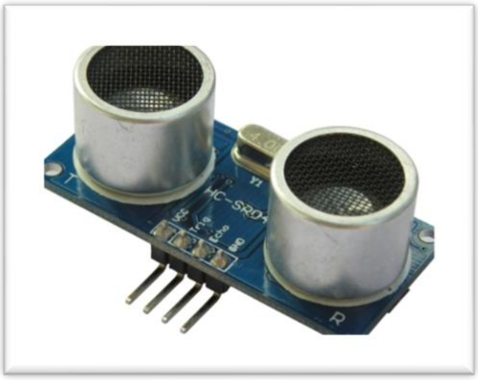
2.2 DISTANCE SENSORS

2.2.1 Ultrasonic sensors

- **Advantages**
  - do not use much electricity;
  - simple in design;
  - relatively inexpensive;
- **Disadvantages**
  - density, consistency, and material can distort an ultrasonic sensor's readings.

2.2.1.1 HC-SR04

- Working Voltage DC 5 V
- Working Current 15mA
- Range: 2cm - 400cm
- Accuracy: 3mm
- Dimension: 45*20*15mm
- Price: about $2/1 piece



HC-SR04

Ultrasonic sensors are popular for their price and reliability. Laser rays can be in some outdoor environment disrupted and in these cases, ultrasonic sensors can take a place. With this type of ultrasonic sensor (HC-SR04) is really easy to work and implement. They work very well with Arduino microcontrollers. Though we have chosen 360° laser sensor, which is described further, these sensors can be buy in next phase of project, if there will be some problems with laser sensor.

2.2.2 Infrared sensors

- **Advantages**
  - can detect infrared light from far distances over a large area;
  - operate in real-time;
  - can receive infrared light that is irradiated from both living and non-living objects.

Sharp GP2Y0A02YK0F

- **Disadvantages**
  - incapable of distinguishing between objects that irradiate similar thermal energy levels.

2.2.2.1 Sharp GP2Y0A02YK0F

- Analog output varies from 2.8V at 15cm to 0.4V at 150cm
- Distance measuring range: 20 to 150 cm
- Package size: 29.5×13×21.6 mm
- Supply voltage: 4.5 to 5.5 V
- Price: €14.15

This type of infrared sensor is a distance measuring sensor unit, composed of an integrated combination of PSD (position sensitive detector), IRED (infrared emitting diode) and signal processing circuit. The variety of the reflectivity of the object, the environmental temperature and the operating duration are not influenced easily to the distance detection because of adopting the triangulation method. This device outputs the voltage corresponding to the detection distance. So, this sensor can also be used as a proximity sensor. It is also suitable for robot applications.

2.2.3 Laser sensors

- **Advantages**
  - Higher accuracy
  - Fast acquisition and processing
  - Higher speed of measurement
- **Disadvantages**
  - Higher costs

2.2.3.1 RPLIDAR 360° A2

- 360 degree laser scanner development kit
- Omnidirectional laser scan
- User configurable scan rate
- Ideal Sensor for robot localization & mapping
- Price: €412.61

RPLIDAR 360° A2

RPLIDAR A2 is the next generation low cost 360 degree 2D laser scanner (LIDAR) solution. It can take up to 4000 samples of laser ranging per second with high rotation speed. The system can perform 2D 360-degree scan within a 6-meter range. The generated 2D point cloud data can be used in mapping, localization and object/environment modeling. The typical scanning frequency of the RPLIDAR A2 is 10hz (600rpm). Under this condition, the resolution will be 0.9°. And the actual scanning frequency can be freely adjusted within the 5-15hz range according to the requirements of users. The RPLIDAR A2 adopts the low cost laser triangulation measurement system, which makes the RPLIDAR A2 has excellent performance in all kinds of indoor environment and outdoor environment without direct sunlight exposure. Meanwhile, before leaving the factory, every RPLIDAR A2 has passed the strict testing to ensure the laser output power meet the standards of FDA Class I.

It is suitable for applications as obstacle avoidance, autonomous mapping, route planning or navigation. From that reason, we have chosen this type of distance sensor for our application to measure distance from obstacle around the car robot.

2.3 BATTERIES

2.3.1 Gogen Power Bank 12000 mAh black-gray
Key features

Capacity 3.7 V - 12000 mAh / 44.4 Wh

Input: Micro USB 5 V / 2 A

Output: 2 x USB (5 V / 2.1 A and 5 V / 2.5 A)

LED charge status indicator

LED flashlight

Power on the road

Thanks external rechargeable battery GoGEN high capacity 12000 mAh will make your travel easier, because your device as smartphone, MP3 and MP4 player, GPS navigation, outdoor camera, camera or tablet will be able to use a much longer without the fear that the end of the stay You will no longer have the "juice" to operate the device. Conventional mobile phones and recharge at least 5 times, depending on the capacity of the battery being charged devices. 5 V outputs with 2.1 and 2.5 and allows you to charge the device with higher current consumption such as tablets and mobile phones from Apple.

Fast charging

Thanks to the current 2.5 A can with UPS GoGEN charge your device up to two times faster than conventional chargers. The battery can use almost any mobile device, which can be powered via the USB port. LED will show the remaining power of the backup source.

Gogen Power Bank 12000 mAh black-gray

Price: 25.99 Eur

2.3.2 USB Battery Pack for Raspberry Pi - 10000mAh - 2 x 5V outputs
Description

A large-sized rechargeable battery pack for Raspberry Pi or anything else that uses 5V. This pack is intended for providing a lot of power to an GPS, cell phone, tablet, etc. But we found it does a really good job of powering other miniature computers and micro-controllers.

Inside is a massive 10,000mAh lithium ion battery, a charging circuit (you charge it via the USB cable attached), and two boost converters that provide 5VDC, 1A and 2A each via a USB A port. (The markings indicate one is good for 1A and one is good for 2A) The 2A output is best for charging tablets or other really power-hungry devices. But either can be used for when you want to power a Beagle Bone or Raspberry Pi, wifi adapters, maybe even small displays.

The charging circuit will draw 1A from a 5V supply (plug a microUSB connector into the pack and then to a computer or wall adapter). You can charge and power something at the same time but the output switches to the USB input when charging so the output voltage may fluctuate. Its not good as a 'UPS' power supply for an embedded linux board, although microcontrollers like Arduino may not care about the voltage drop as much. Also, there's ~80% efficiency loss on both ends so if you charge it at 1A and draw 1A at the same time, the battery pack will eventually go empty. However, if you're powering something thats 500mA or less, you can keep it topped up no problem. Also, when you start and stop charging the pack, it will flicker the output, this can cause a 'power sensitive' device like the Pi or an iPhone to reset on the power supply. If using it with a low current load, say under 100mA, the pack may 'fall asleep' - you can use this circuit to keep the pack awake.

2 USB Battery Pack for Raspberry Pi - 10000mAh

2.3.3 Xiaomi Power Bank 20000mAh White

This modern and elegant Power Bank features an ultra-high capacity of 20 000 mAh which allows for multiple recharge of most devices. This external source can be used for charging mobile phones, iPods, GPS navigation, MP3 players, cameras and digital cameras. Appreciate the large capacity of this battery on long trips, road trips and holidays, wherever there is no access to power network.

Key Features

Power Bank with a lightweight and durable aluminum body
A pair of USB to charge two devices simultaneously
Rounded edges for easy grip
High capacity sufficient for multiple phone recharge
Support for fast charging (DC 5V / 2A 9V / 2A 12V / 1.5A)
LEDs indicating the battery status
Compatible with all USB devices
Li-Ion battery with a capacity of 20,000 mAh
Practical and Neat

Integrated Li-Ion battery can be easily recharged via the USB connector. LEDs will indicate the actual state of your battery. Cutting-edge control microchips offer safe protection against over-voltage, over-heating, over-charging and discharging. This Power Bank features a sleek white casing with an elongated shape that fits comfortably to your palm. With this excellent backup battery your devices will always be ready to use.

Xiaomi Power Bank 20000mAh White

2.4 CAR PLATFORMS

2.4.1 GEARS SMP Mobile Platform

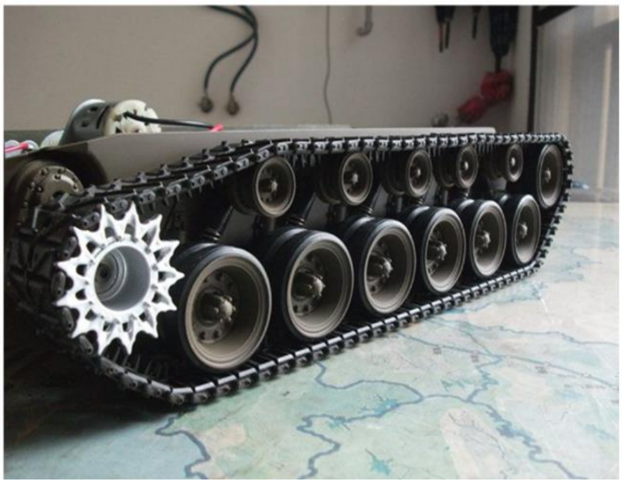
- Robust aluminum chassis for your RC or autonomous robot experimentation
- Innovative suspension system
- Customizable using GEARS aluminum parts
- Additional payload capacity: 8,1 kg
- Does not include encoders
- 0.46 m x 0,50 m x 0,33 m
- Price: €1,500.07 (without encoders)

GEARS SMP Mobile Platform

The GEARS-SMP Mobile Platform was conceived for educational programs looking to integrate robotic sensors and control in a robust mobile platform. The platform can be used indoors and outdoors and navigates the terrain using an innovative suspension system and skid steering. Although the standard version has a 4.5" ground clearance, the entire platform can be customized, raised or lowered or added to using GEARS-EDS parts sold separately.

2.4.2 Track Chassis

- Motor voltage: 6V-12V
- 0.96 x 0.55 x 0.25 m
- Price: $88.00
- Motor speed:
    - 3V 6915 turn 0.52A
    - Turn 0.66A 6V
- Drive gearbox ratio: 39.25: 1



Track Chassis

Big tank chassis provide much better driving control with used tracks. This platform also has a lot of space for placing our components on the top of the chassis. The seller did not give a lot of information about this platform.

2.4.3 C37 4WD Car

- Car body: Aluminum Alloy
- 400* 300*130 mm
- Working voltage: 12V
- The Car whole weight: 2 kg
- Working carrying capacity: 18kG
- Price: $128.34

3 C37 4WD Car

The platform has four robust wheels, which can provide better stability in rough surface. Although overall chassis dimensions are not too big, there is possibility to mount bigger chassis above the wheels, where we can put all components.

2.4.4 6WD ATR RC with 90mm motors

- IG90 gear motors
- ATR frame: 0.35 x 0.91 m
- Length of chassis: 1.04 m
- 35Ah battery
- Price: $2,499.00

6WD ATR RC with 90mm motors

This is a rugged frame made of 0,47cm thick aluminum to accept IG90 gear motors. The aluminum is all laser cut and CNC bent for an exact fit-up.

The IG90 ATR frame is 0,35m wide x 0,91m long. The sides are 5 cm high (bottom edge to top surface). As configured with 0,33cm tiller tires shaft and wheel sets it has a ground clearance of about 12,7cm and total width (wheel edge to wheel edge) of about 0,69m. The length of chassis is about 1,04m (wheel edge to wheel edge). The overall height is just the wheel diameter of 33cm.

2.4.5 Pre-Built 4WD IG52

- Fully assembled and ready to run
- IG52 24VDC 285 RPM Gear Motors
- Spektrum Transmitter and Receiver 2.4GHz
- 12 Volt 18Ah Sealed Lead Acid Battery (run in series for 24V)
- Speed: 3 mph
- 0.74 m x 0,74 m
- Payload of approximately 18-27 kg

Pre-Built 4WD IG52

This is a robot series that is designed to drive over just about any terrain for use with surveillance, academic research, and most practical robotic applications. It works on any indoor surface and most outdoor surfaces. The platform is already configured, but custom configuration is possible.

2.4.6 GRIZZLY (RUV)

- industry-leading robot workhorse
- four independently driven wheels
- 1750 x 1282 x 811 mm
- Max Payload: 600 kg
- Speed: 18 mph
- 16-degree front axle articulation
- 200 Ah, 48V sealed lead acid battery pack
- User Power: 5V, 12V, 24V and 48V
- Unknown price

GRIZZLY (RUV)

Grizzly is a large all-terrain robotic utility vehicle that offers the performance of a tractor and the precision of an industrial robot. This all-electric workhorse has a maximum continuous drawbar force of 1400 lbf and a payload capacity of 600kg.

Grizzly is built for the most demanding outdoor environments, making it ideal for mining, military and agricultural research. It interfaces with a variety of payloads, including single-point hitch implements as well as all of Clearpath's sensing, computing and manipulator packages.

Grizzly has four independently driven wheels, each with high-resolution (2500 counts per revolution) encoders and finely tuned closed-loop control. The result is precise linear position control even at low speeds.

Conclusion from analysis of car platforms

After discussion with all of us, we realized that none of the above platforms are suitable for our project. They have either too small dimension, or the custom configuration will bring a lot of problems. Therefore, we have decided to build our own car platform. It means we must buy all parts (wheels, motors, chassis) independently and put it together.

For lack of time, it is easier if our solution will not provide steering by turning front wheels. Changing direction will be allowed by moving wheels on one side (the wheels on the second side can move in opposite way).

The chassis should have dimension around 800x600 mm. Our member Marek has experiences with welding, so he can construct chassis with our requirements.

2.5 BOARDS

In this section, analysis of available boards is presented. We have chosen four boards - Raspberry Pi 3 Model B, DE1-SoC-MTL2, Banana Pi-M2+ and Arduino Uno.

2.5.1 Raspberry Pi 3 Model B

Raspberry Pi 3 is the third generation Raspberry Pi. For Raspberry Pi 3, Broadcom have supported us with a new SoC, BCM2837. This retains the same basic architecture as its predecessors BCM2835 and BCM2836, so all those projects and tutorials which rely on the precise details of the Raspberry Pi hardware will continue to work. The 900MHz 32-bit quad-core ARM Cortex-A7 CPU complex has been replaced by a custom-hardened 1.2GHz 64-bit quad-core ARM Cortex-A53. Combining a 33% increase in clock speed with various architectural enhancements, this provides a 50-60% increase in performance in 32-bit mode versus Raspberry Pi 2, or roughly a factor of ten over the original Raspberry Pi.

Raspberry Pi 3 Model B Specification

Processor Chipset	Broadcom BCM2837 64Bit Quad Core Processor powered Single Board Computer running at 1.2GHz
Processor Speed	QUAD Core @1.2 GHz
RAM	1GB SDRAM @ 400 MHz
Storage	MicroSD
USB 2.0	4x USB Ports
Max Power Draw/voltage	2.5A @ 5V
GPIO	40 pin
Ethernet Port	Yes
WiFi	Built in
Bluetooth Low Energy (BLE)	Built in
CSI camera port/DSI display port	Built in/Built in

2.5.2 DE1-SoC-MTL2

The DE1-SoC-MTL2 Development Kit is a comprehensive design environment with everything embedded developers need to create processing-based systems. The DE1-SoC-MTL2 delivers an integrated platform including hardware, design tools, and reference designs for developing embedded software and hardware platforms in a wide range of applications. The fully integrated kit allows developers to rapidly customize their processor and IP to best suit their specific application. The DE1-SoC-MTL2 features a DE1-SoC development board targeting Altera Cyclone® V SX SoC FPGA, as well as a capacitive LCD multimedia color touch panel which natively supports five points multi-touch and gestures.

The all-in-one embedded solution offered on the DE1-SoC-MTL2, in combination of a LCD touch panel and digital image module, provide s embedded developers the ideal platform for multimedia applications with unparallel processing performance. Developers can benefit from the use of FPGA-based embedded processing system such as mitigat ing design risk and obsolescence, design reuse, lowering bill of material (BOM) costs by integrating powerful graphics engines within the FPGA.

DE1-SoC-MTL2 Specification

Cyclone V SE SoC—5CSEMA5F31C6N	Dual-core ARM Cortex-A9 (HPS) 85K programmable logic elements 4,450 Kbits embedded memory 6 fractional PLLs
Memory Device	64MB (32Mx16) SDRAM for the FPGA 1GB (2x256MBx16) DDR3 SDRAM for the HPS microSD card socket for the HPS
Peripherals	Two port USB 2.0 Host UART to USB (USB Mini B connector) 10/100/1000 Ethernet PS/2 mouse/keyboard I2C multiplexer
Connectors	Two 40-pin expansion headers One 10-pin ADC input header One LTC connector (one Serial Peripheral Interface (SPI) master ,one I2C bus, and one GPIO interface)
Display	24-bit VGA DAC
Sensors	G-Sensor on HPS
Switches, Buttons and LEDs	5 user keys (4 for the FPGA and 1 for the HPS) 10 user switches for the FPGA 11 user LEDs (10 for the FPGA and 1 for the HPS) 2 HPS reset buttons (HPS_RESET_n and HPS_WARM_RST_n) Six 7-segment displays
Power	12V DC input

2.5.3 BANANA Pi-M2 +

Banana Pi M2 is a second generation single board computer with an upgraded SoC to provide even more power for computing tasks. It features high performance quad-core SoC, 1GB of DDR3 SDRAM, Gigabit Ethernet, 4 USB, and HDMI connection. It can run on a variety of operating systems including Android, Lubuntu, Ubuntu, Debian, and Raspbian.

CPU	A31S ARM Cortex-A7™ Quad-core 256KB L1 cache 1MB L2 cache
GPU	PowerVR SGX54MP2 Comply with OpenGL ES 2.0 OpenCL 1x,DX9_3
Memory	1GB DDR3 (shared with GPU)
Storage Support	MicroSD Card(up to 64GB)
Onboard Network	10/100/1000 Ethernet RJ45
WiFi	WiFi 802.11b/g/n
Video In	Parallel 8-bit camera interface
Video Out	HDMI,LVDS/RGB (no composite video)
Audio Out	3.5 mm Jack and HDMI
Audio In	On board microphone
Power Source	5V DC @ 2A (4.0mm/1.7mm barrel plug - centre positive) or USB OTG
USB Ports	4x USB 2.0
Buttons	Power/Reset: next to Camera Connector
GPIO	GPIO,UART,I2C BUS,SPI BUS,ADC,PWM,+3.3V,+5V,GND
LED	Power key and RJ45
OS	Android and Linux etc.OS

2.5.4 Arduino UNO

Arduino/Genuino Uno is a microcontroller board based on the ATmega328PIt has 14 digital input/output pins (of which 6 can be used as PWM outputs), 6 analog inputs, a 16 MHz quartz crystal, a USB connection, a power jack, an ICSP header and a reset button. It contains everything needed to support the microcontroller.

Microcontroller	ATmega328
Operating Voltage	5V
Input Voltage (recommended)	7-12V
Input Voltage (limits)	6-20V
Digital I/O Pins	14 (of which 6 provide PWM output)
Analog Input Pins	6
DC Current per I/O Pin	40 mA
DC Current for 3.3V Pin	50 mA
Flash Memory	32 KB (ATmega328) of which 0.5 KB used by bootloader
SRAM	2 KB (ATmega328)
EEPROM	1 KB (ATmega328)
Clock Speed	16 MHz

2.6 Camera

For our vehicle, we will need 2 cameras to monitor the surroundings for good navigation on the road. One of these cameras is supposed to record the traffic signs, while the other will be used as an infrared sensor for road lines. The size of the cameras is very important, because we are working with a fairly small vehicle with limited space and carrying capacity. Also our budget is not too big, so the price has to be reasonable.

2.6.1 Outdoor Full HD WDR PoE Day/Night Bullet Network Camera - DCS-7513

Camera Hardware Profile

- 1/2.8” 2 Megapixel progressive CMOS sensor
- 30 meter IR illumination distance
- Minimum illumination: 0 lux with IR LEDs on
- Built-in Infrared-Cut Removable (ICR) Filter module
- 10x digital zoom
- 3 to 9 mm motorised varifocal lens
- Aperture: F1.2
- Angle of view (16:9)
- (H) 121.2° to 38.1°
- (V) 62.1° to 21.3°
- (D) 148.4° to 43.8°

Camera Housing

- IP-66 compliant weatherproof housing
- Cable management bracket

Image Features

- Configurable image size, quality, frame rate, and bit rate
- Time stamp and text overlays
- Configurable motion detection windows
- Configurable privacy mask zones
- Configurable shutter speed, brightness, saturation, contrast, sharpness, zoom, focus, and aperture

Video Compression

- Simultaneous H.264/MPEG-4/MJPEG format compression
- H.264/MPEG-4 multicast streaming
- JPEG for still images

Video Resolution

- 16:9 at 1920 x 1080,1280 x 720, 800 x 450, 640 x 360, 480 x 270, 320 x 176, 176 x 144 up to 30 fps
- 4:3 at 1440 x 1080, 1280 x 960, 1024 x 768, 800 x 600, 640 x 480, 320 x 240, 176 x 144 up to 30 fps

Audio Support

- G.726
- G.711

External Device Interface

- 10/100 BASE-TX Ethernet port with PoE
- 1 DI / 1 DO
- DC12 V, 100 mA output
- SD/SDHC card slot
- Audio input/output
- DI/DO connector 12 V DC output

Network Protocols

- IPv6
- IPv4
- TCP/IP
- UDP
- ICMP
- DHCP client

- NTP client (D-Link)
- DNS client
- DDNS client (D-Link)
- SMTP client
- FTP client
- HTTP / HTTPS
- Samba client
- PPPoE
- UPnP port forwarding
- RTP / RTSP/ RTCP
- IP filtering
- QoS
- CoS
- Multicast
- IGMP
- ONVIF compliant

Security

- Administrator and user group protection
- Password authentication
- HTTP and RTSP digest encryption

System Requirements for Web Interface

- Browser: Internet Explorer, Firefox, Chrome, or Safari

Event Management

- Motion detection
- Event notification and uploading of snapshots/video clips via e-mail or FTP
- Supports multiple SMTP and FTP servers
- Multiple event notifications
- Multiple recording methods for easy backup

Remote Management

- Take snapshots/video clips and save to local hard drive or NAS via web browser
- Configuration interface accessible via web browser

Operating Systems

- Windows 7/Vista/XP/2000

D-ViewCam™ System Requirements

- Operating System: Microsoft Windows 7/Vista/XP
- Web Browser: Internet Explorer 7 or higher
- Protocol: Standard TCP/IP

D-ViewCam™ Software Functions

- Remote management
- Control and manage up to 32 cameras
- View up to 32 cameras on one screen
- Management functions provided in web interface
- Scheduled, motion detection, and manual recording triggers

Dimensions

- 223.5 x 97.5 x 90.7 mm

Weight

- 2050 g (with bracket and sunshield)

External Power Adapter

- Input: 100 to 240 V AC, 50/60 Hz
- Output: 12 V 1.25 A

Power Consumption

- 11.02 watts ± 5 %

Temperature

- Operating: -40 to 50 °C (-40 to 122 °F)
- Storage: -20 to 70° C (-4° to 158° F)

Humidity

- Operating: 20% to 80% non-condensing
- Storage: 5% to 95% non-condensing

Certifications

- CE
- CE LVD
- FCC
- C-Tick

Price: 700€

This is a surveilance camera made for outdoot building security. It provides images and also streams of footage in full hd resolution. Being an IP camera, it sends the recorded data using the ethernet connection. Does provide an infrared illumination, so it can work at night.

Since this camera is quite big, it might prove to be a problem to install it on our vehicle. It's price is very high considering our budget. It's built for windows operating system and since we are going to work with the Raspberry Pi motherboard, we'll be working in linux OS.

Outdoor Full HD WDR PoE Day/Night Fixed Bullet Network Camera - DCS-7513

2.6.2 TRENDnet Indoor/Outdoor (TV-IP312PI)

Lens

- Focal length: 4 mm
- Focal depth: 20 cm+
- Aperture: F2.0
- Board lens
- Sensor: 1/3" progressive scan CMOS

Viewing Angle

- Horizontal: 77°
- Vertical: 42°
- Diagonal: 90°

Zoom

- User-defined digital zoom

Minimum Illumination

- IR off: 0.19 lux
- IR on: 0 lux
- 50 meter IR illumination distance
- Smart IR reduces close object overexposure

Video

- D-WDR: 0-100 scale
- 3D Digital Noise Reduction (DNR)
- Shutter speed: 1/3 - 1/100,000
- H.264: 2048 x 1536 up to 20 fps
- MJPEG: 704 x 480 up to 30 fps

Hardware Standards

- IEEE 802.1X
- IEEE 802.3
- IEEE 802.3u
- IEEE 802.3x
- IEEE 802.3af

Device Interface

- 10/100 Mbps PoE port
- Power port (for non-PoE installations, power adapter sold separately (12VDC1A))
- Integrated adjustable mounting base
- LED indicator

Housing

- Weather rating: IP66
- Adjustable sun visor

Network Protocol

- IPv4, IPv6, UDP, TCP, ICMP, ONVIF v2.2, DHCP, NTP, DNS, DDNS, SMTP, FTP, SNMP (v1, v2c, v3), QoS
- NFS, SMB/CIFS
- HTTP, HTTPS
- PPPoE
- UPnP, RTSP, RTP, RTCP, SSL

Operating Temperature

- -30 - 60 °C (-22 - 140 °F)

Operating Humidity

- Max. 95% non-condensing

Certifications

- CE
- FCC
- UL 60950

Dimensions

- 104 x 104 x 243 mm (3.9 x 4.1 x 9.6 in.)

Weight

- 835 g (1.8 lbs.)

Power

- Input: PoE (802.3af)

- Consumption: 9 Watts max.
- Optional Power Supply (Sold separately)
- Output: 12 V DC 1 A
- 5.5 mm barrel connector
- TRENDnet power adapter, model 12VDC1A, sold separately

Management Interface

- Multi-language support: English, French, German, Russian, and Spanish
- IP address filter
- QoS traffic prioritization
- Time, date, and text overlay
- Image settings: brightness, contrast, saturation, sharpness, smart IR, exposure time (1/3 – 1/100,000), video standard, day/night switch, sensitivity, switch time, mirror, D-WDR, white balance, digital noise reduction
- D-WDR enhances video quality in high contrast daytime lighting
- 3D Digital Noise Reduction enhances night vision quality
- Scheduled recording: continuous and motion detection
- Video storage: to computer, NAS, CIFS/SAMBA share or through software
- Motion detection fields: define custom motion detection areas, motion sensitivity, and dynamic motion analysis
- Privacy masks: define custom privacy mask areas
- Tamper detection: email notification if the viewing field darkens suddenly
- Video playback: advanced playback functionality with visual timeline displaying detected motion and scheduled recordings
- Alert messages: storage full, storage error, and illegal login
- Snapshot: real time snapshot, motion detection with schedule, video tamper detection with schedule
- Supported dynamic DNS services: Dyn.com and NO-IP.org
- Management Setting: maximum 32 user accounts
- Supports remote management
- Storage logs: Alarm, Exception, Operation, and others
- Compatibility: Internet Explorer® 9.0 or higher, Firefox® 13.0 or higher, Safari® 4.0 or higher, Chrome™ 24.0 or higher

Price

110€

This is another surveillance IP camera and like the first, it records in high resolution and also has an infrared filter, that can be turned on and off. But also has the size and compatibility issues, however the price is a lot lower and actually reasonable.

TRENDnet Indoor/Outdoor (TV-IP312PI)

2.6.3 Raspberry Pi Camera Module V2 - 8 Megapixel,1080p

Number of Channels	1
Supported Bus Interfaces	CSI-2
Maximum Supported Resolution	3280 x 2464
Maximum Frame Rate Capture	30fps
Dimensions	23.86 x 25 x 9mm
Length	23.86mm
Width	25mm
Height	9mm
Connection	15cm ribbon cable for CSI port
Maximum Operating Temperature	+60°C
Minimum Operating Temperature	-20°C

Price

21€

This camera module is made specifically for the raspberry Pi motherboard. Provides high definition images/footage. With it’s really tiny size it can fit anywhere, it has practically no weight at all. Camera accessible using libraries, e.g. Picamera. Does not have infrared vision.

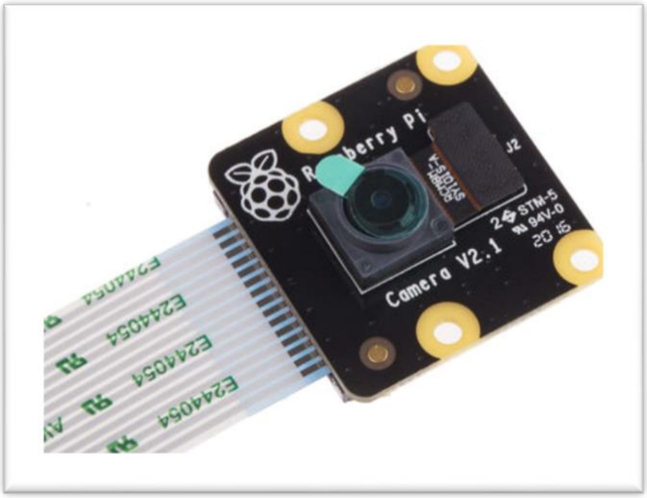
Raspberry Pi Camera Module V2

2.6.4 Raspberry Pi PiNoir Camera V2 Video Module

Number of Channels	1
Supported Bus Interfaces	CSI-2
Maximum Supported Resolution	3280 x 2464
Maximum Frame Rate Capture	30fps
Dimensions	23.86 x 25 x 9mm
Length	23.86mm
Width	25mm
Height	9mm
Connection	15cm ribbon cable for CSI port
Maximum Operating Temperature	+60°C
Minimum Operating Temperature	-20°C

Price 21€

The specifications for this camera are exactly the same as the one before. The only difference between these two camera modules is the absence of the infra-red filter in the lens. To work in the night, this module would need an infrared illuminator, however i think for our purposes it is not needed.



Raspberry Pi PiNoir Camera V2 Video Module

2.7 DE-Hermes Switch 3-1 BRR

The DE-Switch Hermes 3-1 BRR is a combined switch ECU that is designed for application development and evaluation of Deterministic Ethernet for in-vehicle network architectures considering multiple communication standards, including:

- Audio-Video Bridging (AVB),
- Time-Sensitive Networking (TSN), and
- Time-Triggered Ethernet in combination with a BroadR-Reach® physical layer.

Deterministic Ethernet enables the convergence of critical and non-critical application data streams on one network. The DE-Switch Hermes 3-1 BRR enables the evaluation of in-vehicle network requirements for diagnostics, control applications, infotainment and advanced driver assistance systems (ADAS).

It can be deployed to show the full potential for the next generation of Ethernet-based domain architectures using Deterministic Ethernet.

Specifications:

Dimensions (L x W x H):	146.6 x 92 x 38 mm
Weight:	315 g (with housing)
	400 g (weight of cable harness)
Power Supply:	Nominal: 12 V / 24 V
	Absolute maximum ratings: 6 to 36 V

Fields of Application:

- Automotive
- Buses and trucks
- Farming and off-highway

The DE-Switch Hermes 3-1 BRR

External Interfaces

The DE-Switch Hermes 3-1 BRR has

- **3** BroadR-Reach® physical layer interfaces that enable **100 Mbit/s full-duplex** communication over unshielded twisted single pair (UTSP) cabling,
- **one 1-Gbit/s** Ethernet port (100/1000Base-Tx),
- **1** RS-232 serial interface

The DE-Switch Hermes 3-1 BRR has the following standard interfaces, such as CAN and FlexRay™, and digital and analog I/Os for customized evaluation projects.

- **3** CAN interfaces (125 kbit/s up to 1 Mbit/s),
- **1** FlexRay™ interface (channel A and B),
- **4** analog inputs (0 to 5 V or 4 to 20 mA, 0 to 10 V provided by DE-Switch Hermes 3-1 BRR),
- **2** digital timer inputs (0.1 Hz to 20 kHz),
- **4** digital high-side PWM outputs:
    - 3 A permanent
    - 4 A peak
    - 5 A overall maximum

Standards Compliance

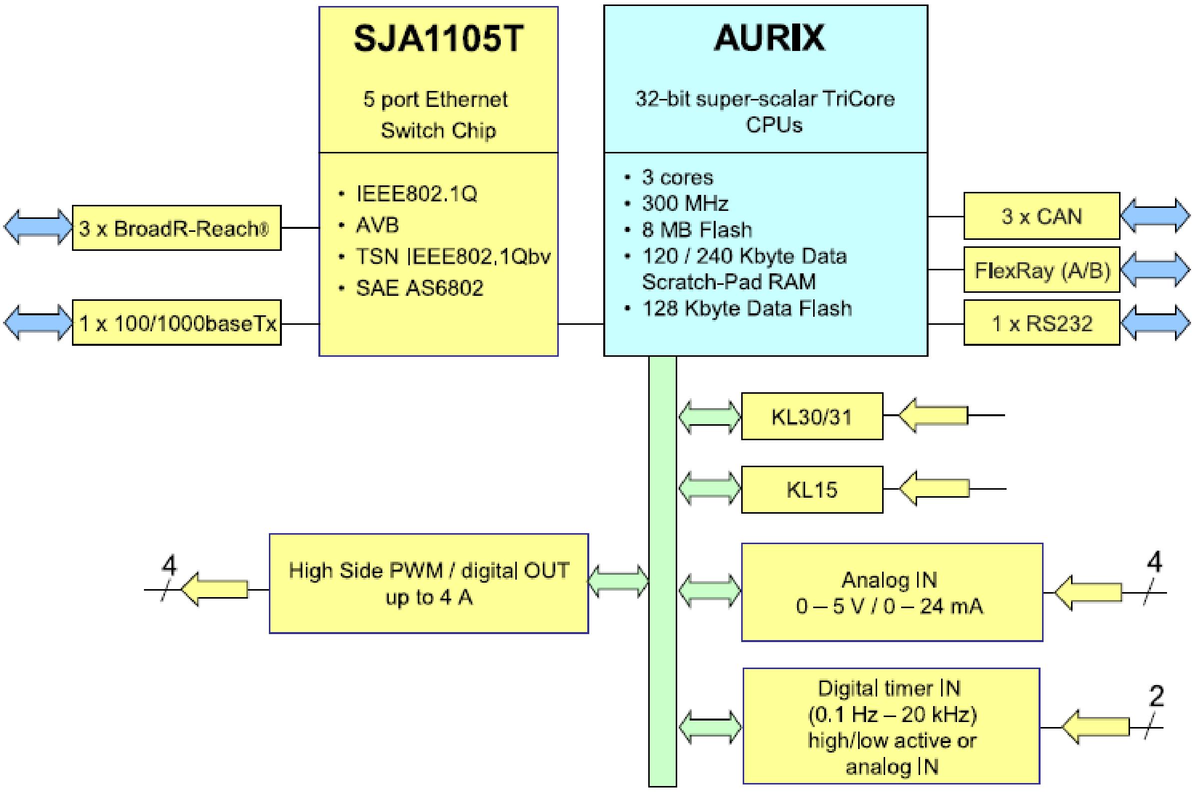
- **IEEE 802.1D™-**2004 (layer 2 switching)
- **IEEE 802.1Q™-**2011 (VLAN support)
- QoS handling based on IEEE 802.1Q PCP bits
- Support for SR Class A, Class B and Class C traffic
- **IEEE 802.1AS™-**2004 (Timing and Synchronization for Time-Sensitive Applications in Bridged Local Area Networks)
- **IEEE 802.1Qbv™-**2015 (Enhancements for Scheduled Traffic)
- **SAE AS6802** (Time-Triggered Ethernet)
- The switch forwards **best-effort traffic** in compliance with IEEE 802.3-2005 (switching).

- The switch forwards **VLAN-tagged frames** according to IEEE 802.1Q (VLAN core capabilities).

Functional Description

- The DE-Switch Hermes 3-1 BRR provides Ethernet for in-vehicle network architectures and implements network switching functionality that is implemented on the NXP SJA1105T automotive Ethernet switch.
- The DE-Switch Hermes 3-1 BRR has 3 x BroadR-Reach® physical layer interfaces that enable 100 Mbit/s full-duplex communication over unshielded twisted pair cabling in addition to one 100/1000Base-Tx port.
- A management CPU is connected with the Ethernet switch via a 100 Mbit Ethernet interface and an SPI configuration interface. The management CPU runs the switch management protocols (for RSTP and IEEE802.1AS). For customized evaluation projects, external interfaces, such as CAN, FlexRay™, it is possible to use analog and digital I/Os.

Following figure with block diagram gives an overview of the main features of the DE-Switch Hermes 3-1 BRR:



Block diagram of the DE-Switch Hermes 3-1 BRR

Primary Components

- **Ethernet Switch**: The Ethernet Switch is an automotive-compliant 5-port Ethernet switch. The device contains a variety of cross-wire media-independent interfaces to connect any kind of physical layer. The control interface is a serial peripheral interface (SPI), which is necessary to read and write internal registers of the switch chip. Four ports are connected via physical interfaces to the ECU connector, and one port is connected to the management CPU.
- **Management CPU**: The management CPU covers all the control and monitoring features of the system. The CPU also loads and stores the configuration for the Ethernet Switch. The device is responsible for the correct setting of the peripherals, which includes the configuration of the switch and the physical layer and the control of the digital and analog I/Os and communication interfaces.
- **100base-T1 BroadR-Reach® Physical Layer**: The physical layer is an OPEN Alliance BroadRReach ®-compliant Ethernet physical layer that is optimized for automotive use cases. The device provides 100 Mbit/s transmit and 100 Mbit/s receive capability over a single unshielded twisted single pair (UTSP) cable, supporting a cable length of at least up to 15 m. The system has three physical layers. The MII of each physical layer is connected to the Ethernet Switch, whereas the medium-dependent interface (MDI) is connected to the ECU connector via an analog front end.
- **Gigabit Physical Layer**: A Gigabit Ethernet transceiver implements the Ethernet physical layer portion of the 100BASE-TX and 1000BASE-T standards. The reduced Gigabit mediaindependent interface (RGMII) is connected to the Ethernet Switch. As the PCB does not have a standard RJ-45 connector, the MDI is connected to the ECU connector via dedicated magnetics HX5008NL.
- **Power supply and reverse polarity protection**: The power supply and reverse polarity protection block contain all the parts that are necessary to provide proper supply voltages for the board electronics. The input voltage range, which is between 6 V and 36 V is protected against reverse polarity. The nominal voltage range is 12 V or 24 V.
- **Communication Interfaces**: The DE-Switch Hermes 3-1 BRR provides additional communication interfaces beside the Ethernet functionality:

  - An RS-232 interface is also connected to the ECU connector as a user interface and for debug purposes.
  - CAN and FlexRay™ interfaces are implemented.
- **Digital and Analog I/O**: The DE-Switch Hermes 3-1 BRR has several control and monitoring features to combine network-control functionality with electronic control functionality in one ECU.
- **4 high-side PWM output** stages up to 3 A with current measurement and digital feedback provide availability to control relays and engines. A summed current of 5 A at the same time is the limit.
- **4 analog inputs** and **2 digital timer** inputs can be used for different sensor applications.

Ethernet ports

The Ethernet Switch has 5 independent ports. The ports are configured as follows:

Port	Description
0	1 Gbit/s Ethernet port (100/1000Base-Tx)
1	BroadR-Reach® channel 0 (100 Mbit/s full-duplex communication over UTSP cabling)
2	BroadR-Reach® channel 1 (100 Mbit/s full-duplex communication over UTSP cabling)
3	BroadR-Reach® channel 2 (100 Mbit/s full-duplex communication over UTSP cabling)
4	100 Mbit/s MAC-MAC interface to management CPU

We are going to use four Hermes switches in our application. Each switch will be connected to one wheel. Switches will be connected to each other in circle topology.

3. SOLUTION DESIGN

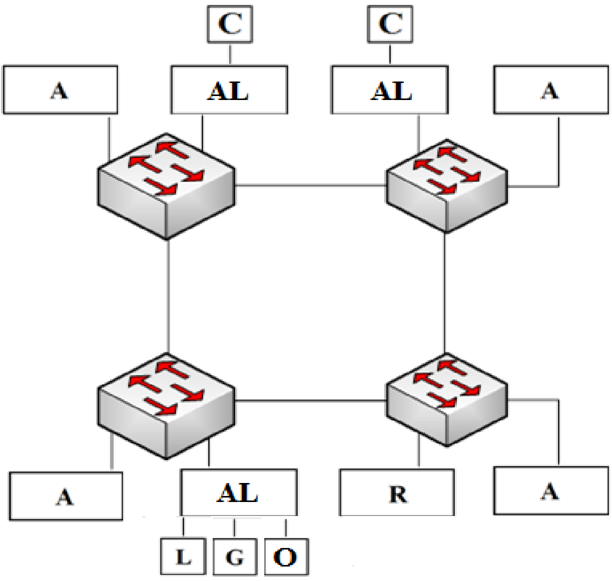
3.1 Logical design

Logical design of car is shown on picture. We will use all four available determinstic Hermes switches, four Arduino Uno boards (A), one Rasbeppry Pi 3 model B board (R), three Altera boards (AL), two cameras (C), laser (L), GPS sensor (G) and digital compass (O).

Each of the Hermes switches has four available ethernet ports. Redundancy is achieved with ring topology, so in case of one link failure, other switches will still be able to communicate. This topology is not resistant against two or more links failures. Full mesh topology would solve this problem but we are limited by the count of physical ports on the switches.

Each Arduino board will control one wheel, but to connect them to the switches, ethernet shields are required, because Arduinos do not have ethernet port by default. Raspberry Pi will send signals to control the speed of each wheel.

Raspberry Pi will act as central point and other boards with sensors will send control information to it. On the front of the car, two cameras will be used. One will handle line assist feature, and the other one will handle road signs recognition. On the top of the model will be 360° degree laser sensor for detections of the obstacles. For car navigation, we will use GPS sensor. Navigation with GPS is described in section 3.3.



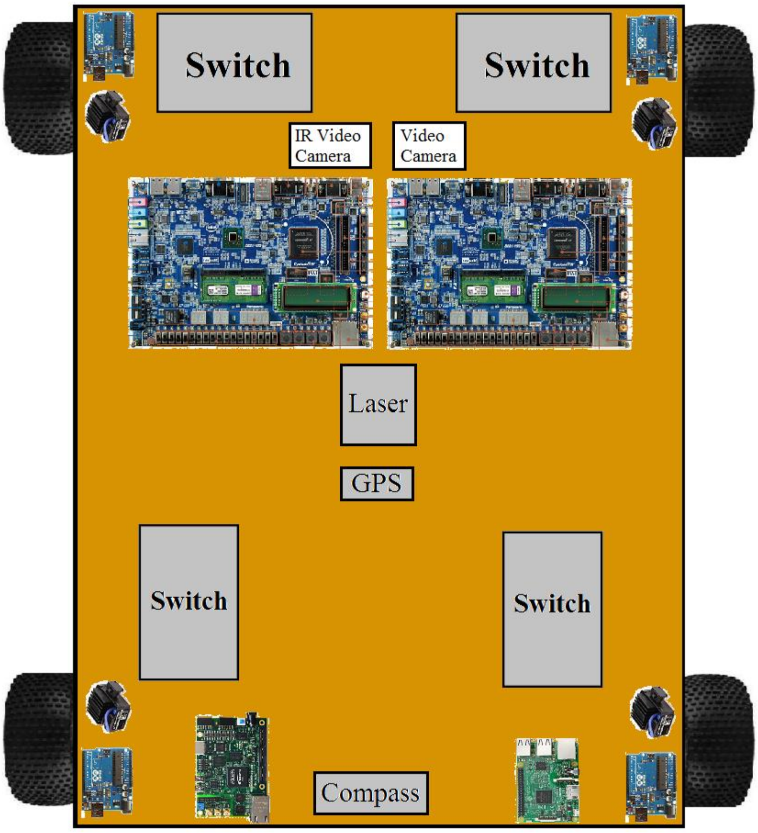
Logical design of car model

3.2 Physical design

Physical design of the car is shown in the picture. There are four wheels which were bought in RC shop. These wheels are from large RC buggy so larger payload on this car is not a problem for them. In every edge of the car an Arduino and regulator are located. Every Arduino controls one motor through a regulator. Therefore, we can achieve smooth speed regulation and reverse drive as well.

Large more powerful Altera boards are located in front part of the car. The first Altera board on the left controls IR video camera for line checking and the second Altera board on the right controls normal video camera for road signs recognition.

Laser is located on the top, in the middle of the car. It is because laser must not have any obstacle in its field of view and it is easier to compute a distance from obstacle if laser is located in the middle of the car. GPS sensor has to be in the middle of the car as well because the car is a larger one so GPS positions in the edges of the car may be different. A compass is located in the back part of the car. There are also located a smaller Altera board and a master raspberry pi board. The batteries in the picture are not shown. They will be placed to suitable position later in this project.



Physical design of the car

3.3 Communication protocol

Communication is based on UDP protocol. The reason why preferring UDP to TCP is that we do not require reliable packet delivery because of „real time“ application. On the contrary, we require to deliver packet fast and without delay to meet requirements of real time. Also, UDP protocol supports broadcast, which can be useful. The communication protocol is shown on screen below.

TYPE	SOURCE BOARD	NUMBER OF SOURCE BOARD	DESTINATION BOARD	NUMBER OF DESTINATION BOARD	TYPE OF MESSAGE	DATA
1B	1B	1B	1B	1B	2B	

Communication protocol

3.3.1 Type field

Field called TYPE is used to distinguish if packet is send from central unit or to central unit. It has size of 1B.

TYPE	message from central unit	message to central unit
IDENTIFICATOR	0x00	0x01

Type field

3.3.2 Source board field

Source board field is used to distinguish which board send packet. Value 0 stands for Arduino, 1 stands for Raspberry and 2 stands for Altera.

SOURCE BOARD	arduino	raspberry	altera
IDENTIFICATOR	0x00	0x01	0x02

Source board field

3.3.3 Number of source board

The field is set to value of source board that sends packet. So far, we do not have more than four boards so the field can obtain values from 1 to 4.

NUMBER OF SOURCE BOARD	0x01	0x02	0x03	0x04

Number of source board field

3.3.4 Destination board field

Destination board field is similar to source board field. It identifies destination board which packet is send to. Value 0 stands for Arduino, 1 stands for Raspberry and 2 stands for Altera.

DESTINATION BOARD	arduino	raspberry	altera
IDENTIFICATOR	0x00	0x01	0x02

Destination board field

3.3.5 Number of destination board field

This field is similar to field called number of source board field. The field is set to value of destination board that packet is send to. The field can obtain values from 1 to 4.

NUMBER OF DESTINATION BOARD	0x01	0x02	0x03	0x04

Number of destination board field

3.3.6 Type of message field

Message can have different meaning. Value 0 represents notifying of IP address. This type of message is send when IP address is assigned to inform central board. Value 1 stands for instruction from central board to others. Value 2 defines message which servers for acknowledgment of received instruction. Value 3 defines data from infrared camera. Value 4 stands for road side camera and value 5 represents laser data.

TYPE OF MESSAGE	notifying IP address	instruction	instruction ACK	infrared camera data	road side camera data	laser data
IDENTIFICATOR	0x0000	0x0001	0x0002	0x0003	0x0004	0x0005

Type of message field

3.3.7 Laser data message

When laser data are sent, message is as show on screen no 8. First field represents number of available ranges. Next bytes define specific range of angles.

number of ranges (1B)	range #1 (8B)				range #2 (8B)				range #n (8B)			
	start angle (2B)	start distance (2B)	end angle (2B)	end distance (2B)	start angle (2B)	start distance (2B)	end angle (2B)	end distance (2B)	start angle (2B)	start distance (2B)	end angle (2B)	end distance (2B)
n	α	x	β	y	α	x	β	y	α	x	β	y

Laser data message

3.3.8 Road side camera data message

Data from road side camera are sent in format shown on screen no. 9.

Number of road signs	Road sign x1	Road sign x2	Road sign xn
n	#1	#2	#n

Road side camera data message

3.3.9 Infrared camera data message

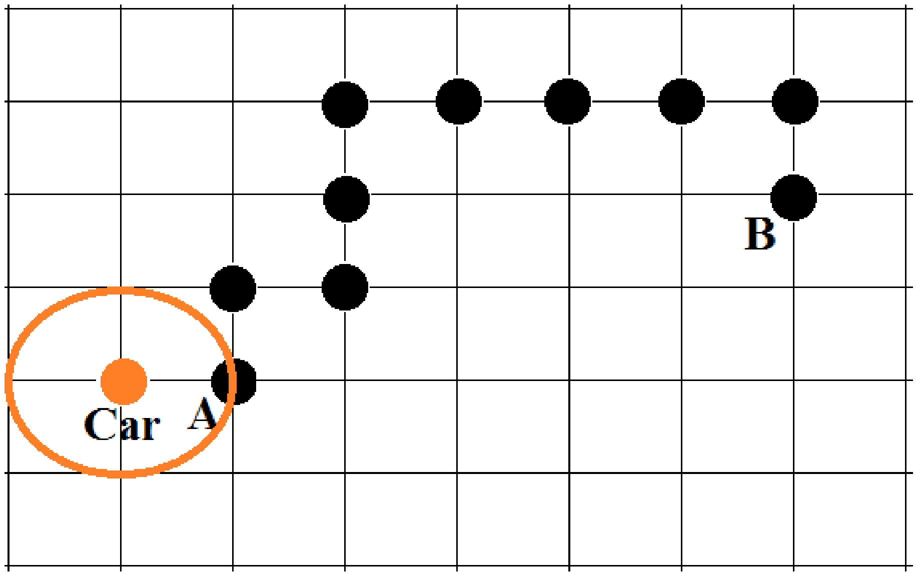
Data from infrared camera are sent in format shown on screen no. 10.

Angle of direction change
x

Infrared camera data message

3.4 Navigation with GPS

GPS navigation will collaborate with digital compass. Assume simplified version of map shown on picture 1. Black dots represent nodes of optimal path from node A to node B.

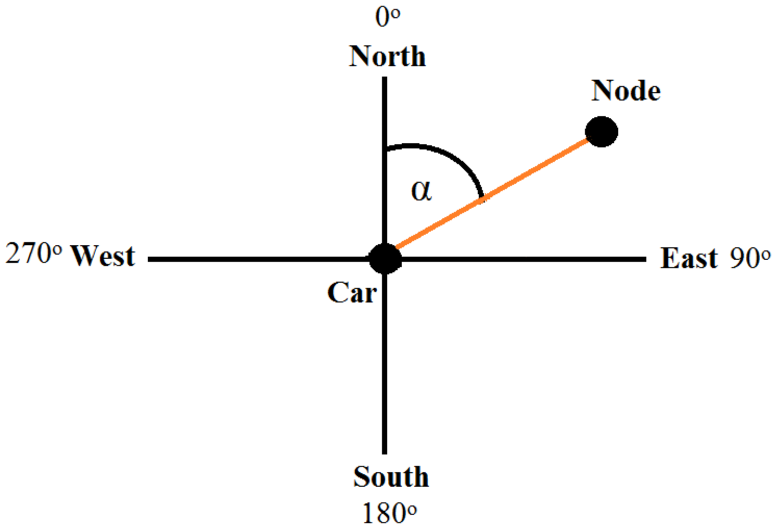


Simplified navigation map

Before navigation, a path from current position to defined destination must be known. This path will be hardcoded in first versions of navigation. Later, tools for finding optimal path (for example based on OpenStreet maps) will be used to compute the best path.

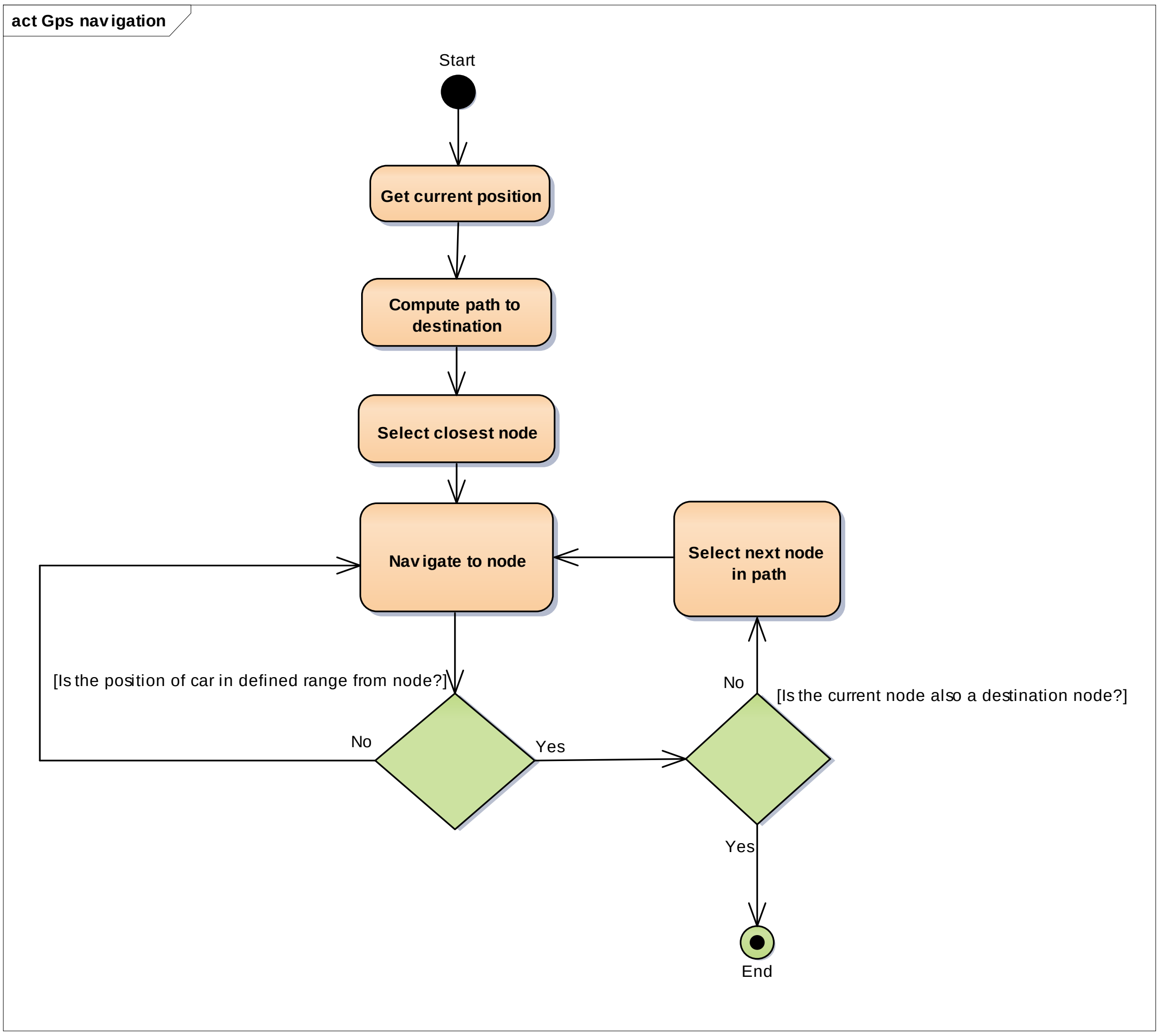
After the path is known, the navigation process begins. Every place in the world can be defined with latitude and longitude. The precision of GPS sensor is around 5 meters, therefore we can only approximately tell where our vehicle is. Defined path will be represented by nodes on the real road. Distance between these nodes must be greater than GPS precision, so we can navigate from one node to another.

Car first needs to determine the closest node of the path. Then the navigation degree to this node will be computed (see picture 2) and sent to central processing unit (Raspberry Pi), which will control the movement of the car to the selected node based on other signals from other sensors. As mention earlier, we cannot accurately tell, if the car is in the selected node. We will consider node reached, when the car will be in the defined range from the selected node.



Calculation of navigation degree

After car reaches the node, then the next node from the path is selected and the navigation process begins from start. Whole process of navigation is shown on diagram 1.



Activity diagram of GPS navigation

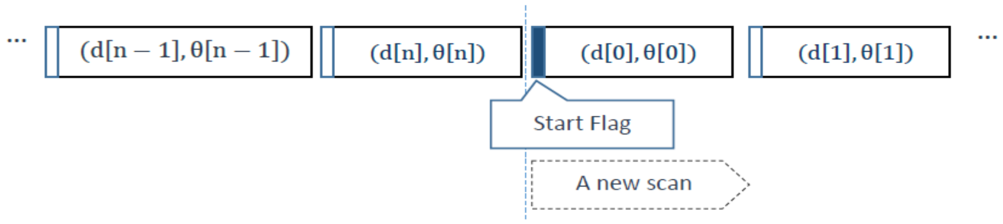
3.5 Laser data processing

RPLIDAR A2 can take up to 4000 samples of laser ranging per second with high rotation speed. The range scan data can be processed via the communication interface of the RPLIDAR and control the start, stop and rotating speed of the rotate motor via PWM.

During the working process, the RPLIDAR will output the sampling data via the communication interface. And each sample point data contains the information in the following table.

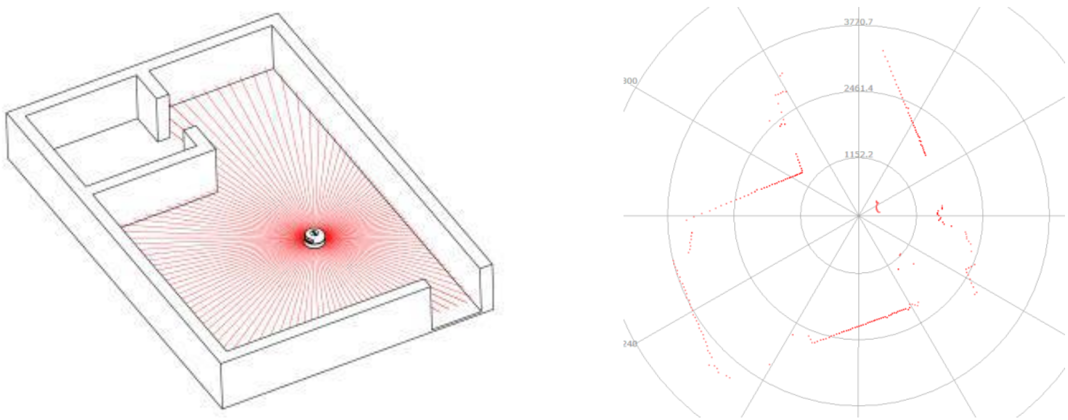
Data type	Unit	Description
Distance	mm	Current measured distance value between the rotating core of the RPLIDAR and the sampling point
Heading	degree	Current heading angle of the measurement
Start Flag	(Bool)	Flag of a new scan
Checksum		The Checksum of RPLIDAR return data

The RPLIDAR Sample Point Data Information



The RPLIDAR Sample Point Data Frames

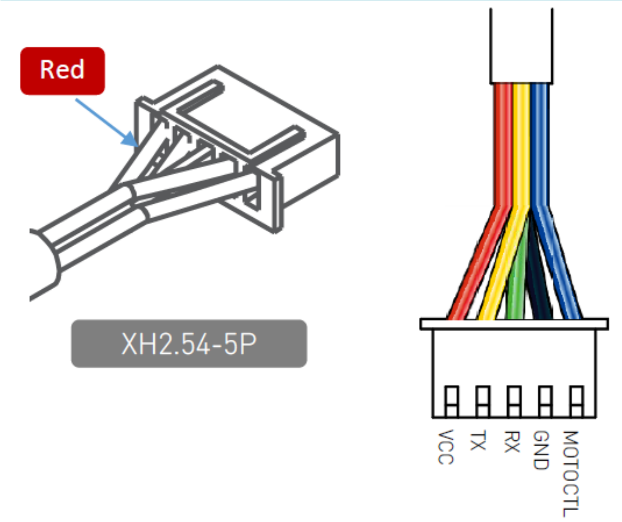
The RPLIDAR outputs sampling data continuously and it contains the sample point data frames in the above figure. Host systems can configure output format and stop RPLIDAR by sending stop command.



The Obtained Environment Map from RPLIDAR Scanning

Communication interface

The RPLIDAR A2 uses separate 5V DC power for powering the range scanner core and the motor system. And the standard RPLIDAR A2 uses XH2.54-5P male socket. Detailed interface definition is shown in the following figure:



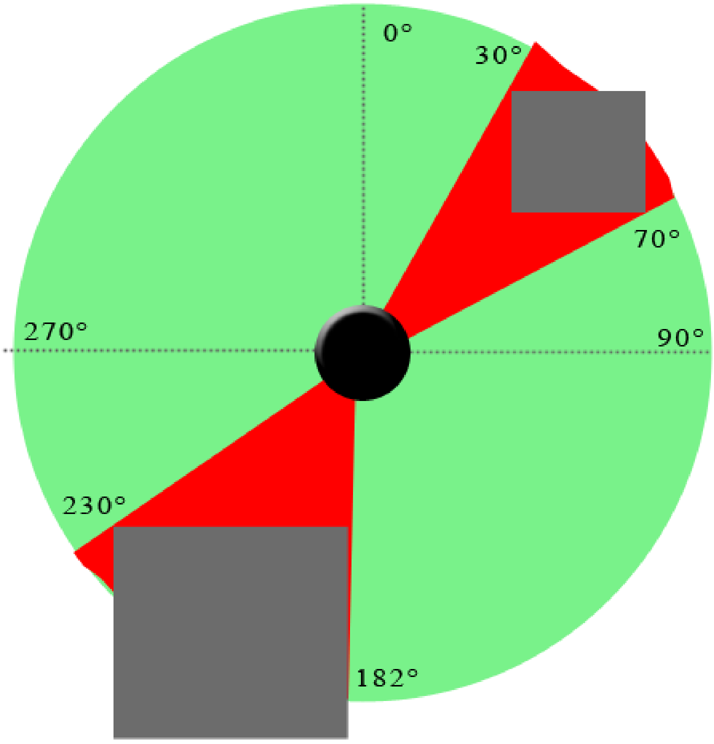
RPLIDAR Power Interface Definition

Color	Signal name	Type	Description	Min	Typical	Max
Red	VCC	Power	Total Power	4.9V	5V	5.5V
Yellow	TX	Output	Serial port output of the scanner core	0V	3.3V	3.5V
Green	RX	Input	Serial port input of the scanner core	0V	3.3V	3.5V
Black	GND	Power	GND	0V	0V	0V
Blue	MOTOCTL	Input	Scan motor /PWM Control Signal (active high, internal pull down)	0V	3.3V	5V

RPLIDAR External Interface Signal Definition

Communication Protocol

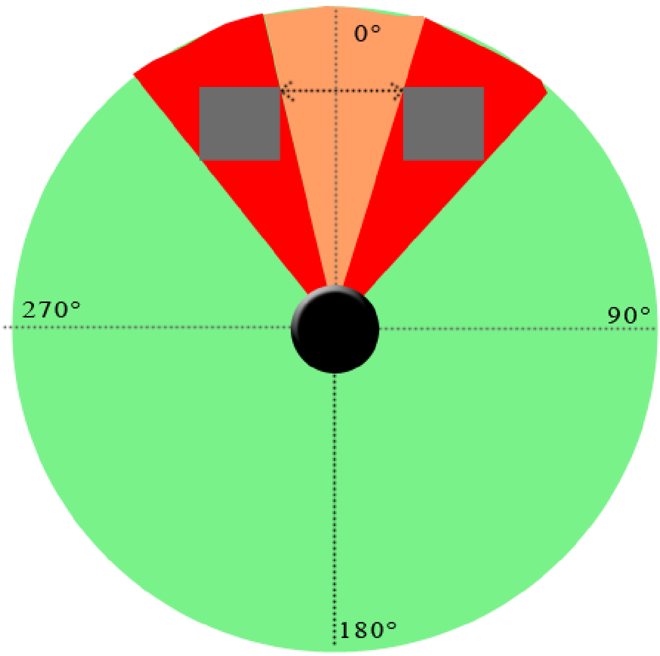
After receiving data from sensor, these data are processing, counting and evaluating for next processing. All counting is performed in microcontroller responsible for communication with laser sensor. This microcontroller sends data to control unit with ranges of angles, where is enough space for passing through this area. With this information, control unit can decide which side to choose in next move. This principle is shown in next figure:



Detecting obstacles around the laser sensor

The microcontroller sends only ranges with enough distance to pass through. In figure above, there are only two ranges with enough space.

For smaller range of angles, there is also necessary to count, if car robot can fit into this space.



Exclusion of angles with short distance between obstacles

The frame structure with open ranges is shown in next figure:

# ranges of ranges	range #1		range #2		range #3		…	
	start angle	end angle	start angle	end angle	start angle	end angle	start angle	end angle
n	x_1	x_2	x_3	x_4	x_5	x_6		

Frame structure

The worst-case scenario is with 180 open ranges. It means, that every second angle meets the distance condition and there is enough space. And vice versa, every second angle does not meet the condition, and there isn't enough space. In this case, it is obvious that robot must stop, because in any direction it hasn't enough space.

So, for number of ranges (value *n*) must be reserved 1 byte. Start and end angle can have value in range from 0 to 360, so there must be reserved 2 bytes.

If there are less than 180 open ranges, the rest of ranges are filled with zeroes. In the example below, there are only 2 open ranges, so only range number 1 and 2 are filled with some values. Rest of them are filled with zeroes. Field number of ranges ensures that these fields are not evaluating.

If the first number is bigger than second one, it means there is overflow and range of angles exceeds zero angle.

# ranges of ranges	range #1		range #2		range #3		…	
	start angle	end angle	start angle	end angle	start angle	end angle	start angle	end angle
2	160	280	300	120	0	0	0	0

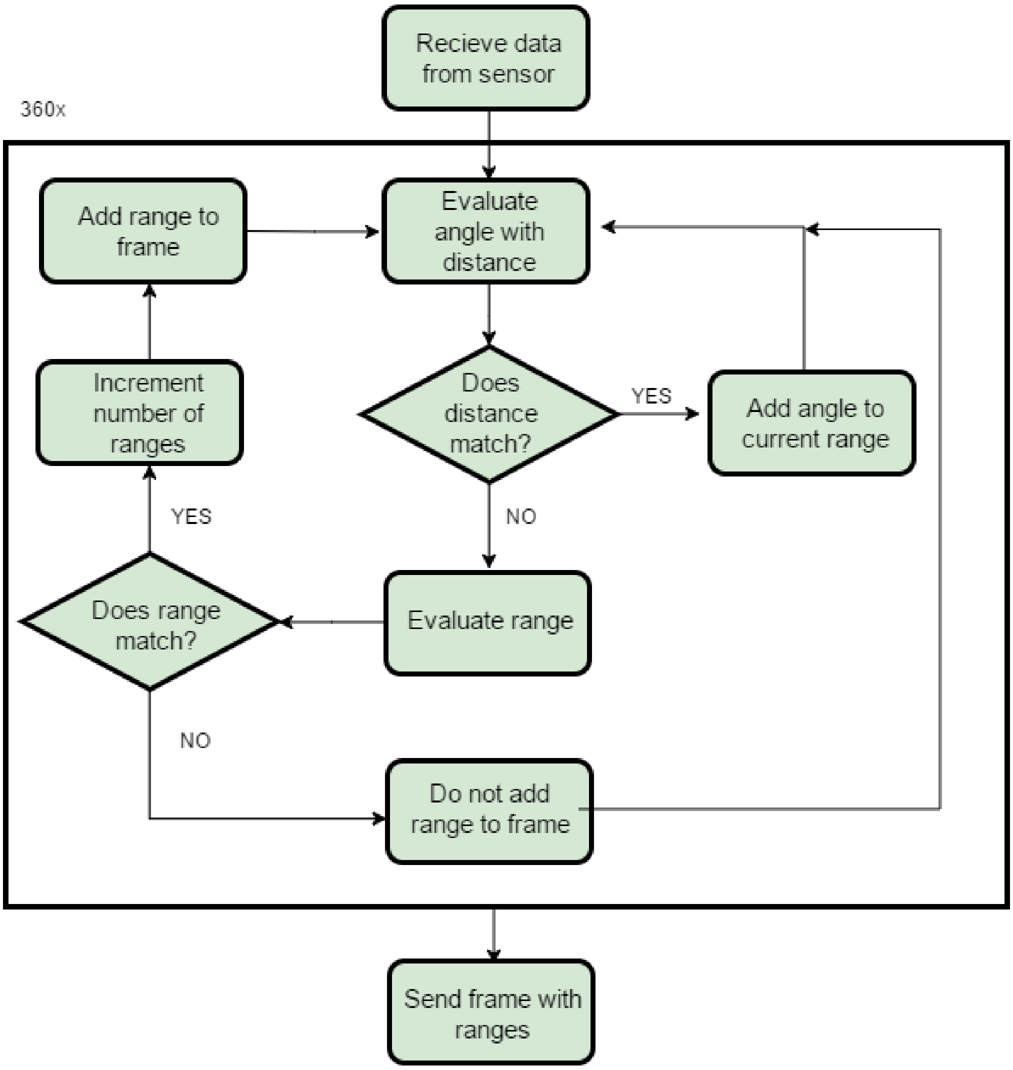
Example with two open ranges

Data processing

Diagram below illustrates data processing from receiving data to sending frame with open ranges.

After receiving data from sensor, each angle is evaluated by distance. If distance matches, it means the distance is less then certain limit distance, angle is added into open range. If not, range is closed. After that, range is evaluated, if there is enough space for passing through. It is counted with trigonometry functions. If range is enough big, it is added into frame with start and end angle.

When all angles are evaluated, the frame can be send to control unit. Since evaluating begins with zero angle, first and last range can be merged before sending.

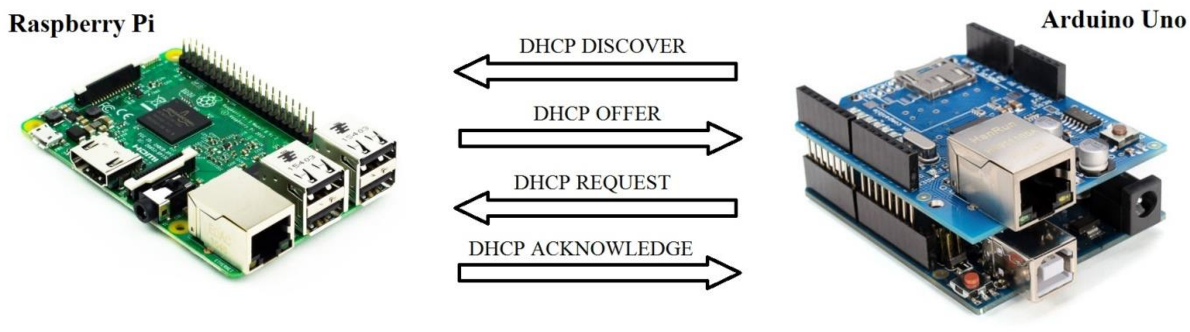


Data processing from laser sensor

3.6 Communication Raspberry Pi - Arduino

In this section a communication between Raspberry Pi and Arduino is described. In our autonomous vehicle, there are four Arduino devices. Every single device controls one motor which is connected to one wheel. After system startup, Arduinos have no IP addresses and they cannot communicate with master Raspberry.

Arduinos are therefore configured as DHCP clients and master Raspberry is configured as DHCP server. After system startup, every Arduino send DHCP DISCOVER message. Then master Raspberry sends DHCP OFFER message. Arduino sends DHCP REQUEST message and master Raspberry sends DHCP ACKNOWLEDGE message. Now every Arduino has its own IP address.



DHCP communication

After this process all Arduinos send initial message to Raspberry. In this message, Arduino tells its IP address and its number. This number is important because master Raspberry use it to recognize which Arduino controls which motor. For example, number 1 means that it is an Arduino which controls front right motor.

Now everything is ready and Raspberry can send instructions to Arduinos. In single instruction there is defined type of message which is in case of instruction ‘01‘ and after this code there is a number in range from 0 to 255 which represents new motor speed. Numbers from 127 to 0 are used to reverse the vehicle. Number 128 is used if we want our vehicle to stay at one place without movement. Last part of numbers from 129 to 255 are used for forward speed regulation.

If master Raspberry wants to send an instruction to Arduino, it uses UDP protocol where there are instruction numbers encoded. When Arduino receives an instruction, it executes this instruction (sets a new wheel speed) and after that it sends an acknowledge message via UDP.

This message is important for Raspberry to know. It can detect failure on Arduino. If battery runs out, Arduino does not send acknowledge messages. This is how Raspberry knows that something happened. If there is at least one Arduino which does not respond, Raspberry immediately stop the vehicle to prevent from any damage.

3.7 Synchronization of sensors

One of the Altera boards have 3 sensors attached to it. GPS, laser and digital compass. For sending deterministic frames, there must be specified window to send information from all three sensors. Therefore, we need to specify time intervals for packet sending.

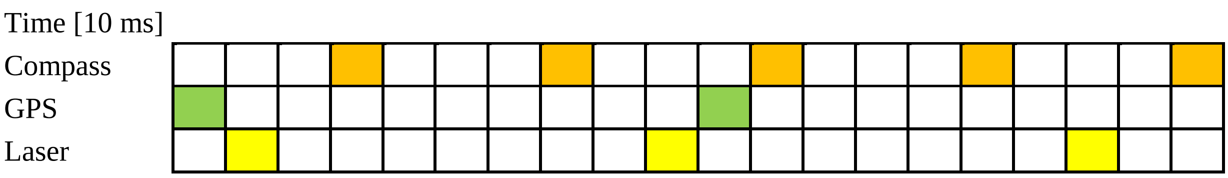
Sensors rates

Each sensor has its own frequency

- **GPS** 1-10 Hz
- **Compass** 1.5, 3, 7.5, 15 (default), 30, 75 Hz
- **Laser** 15 Hz

Synchronization

It is very important that the time slots for sending data do not overlap. To ensure these requirements we need time slots with common divisor. We have chosen 10 Hz (100 ms) for GPS, 30 Hz (34 ms) for compass and 15 Hz (67ms) for Laser. Next, we have to add some extra time for computation and time shaping, so one time slot will have 10 ms and intervals will be 100ms for GPS, 40 ms for compass and 80 ms for laser. Design of timing can be seen on table below.



Time intervals for sending data

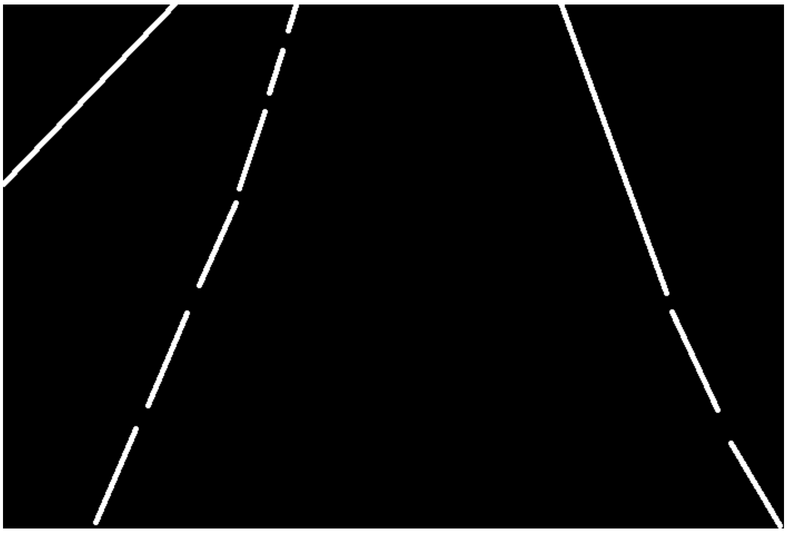
3.8 Camera data processing

3.8.1 Infrared camera

This camera is recording the road to keep track of the lines separating the road lanes. Thanks to the infrared camera, the bright lines should be highlighted.

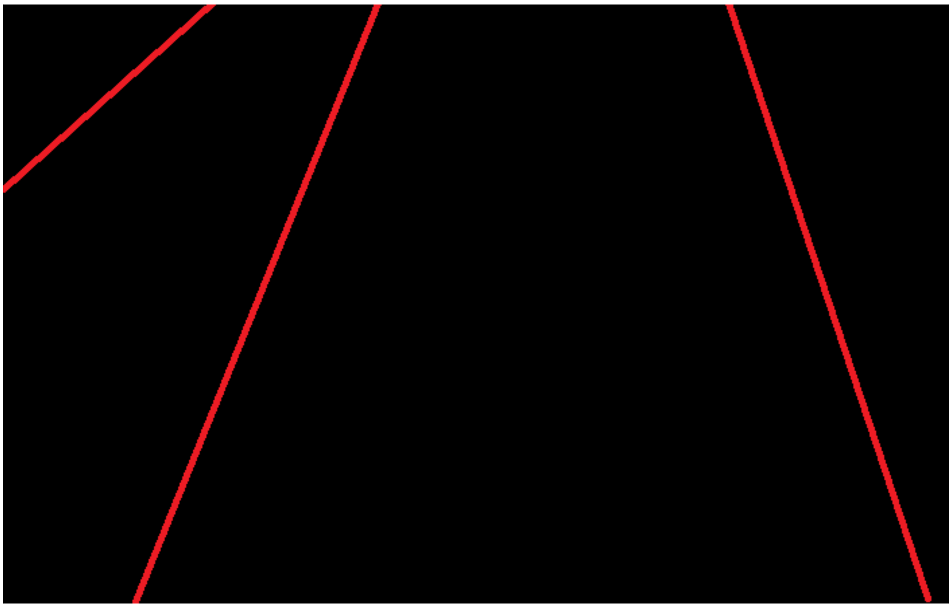
Example input image (image was not taken using infrared camera)

These images are then preprocessed using various filters to only keep the lines (mostly).



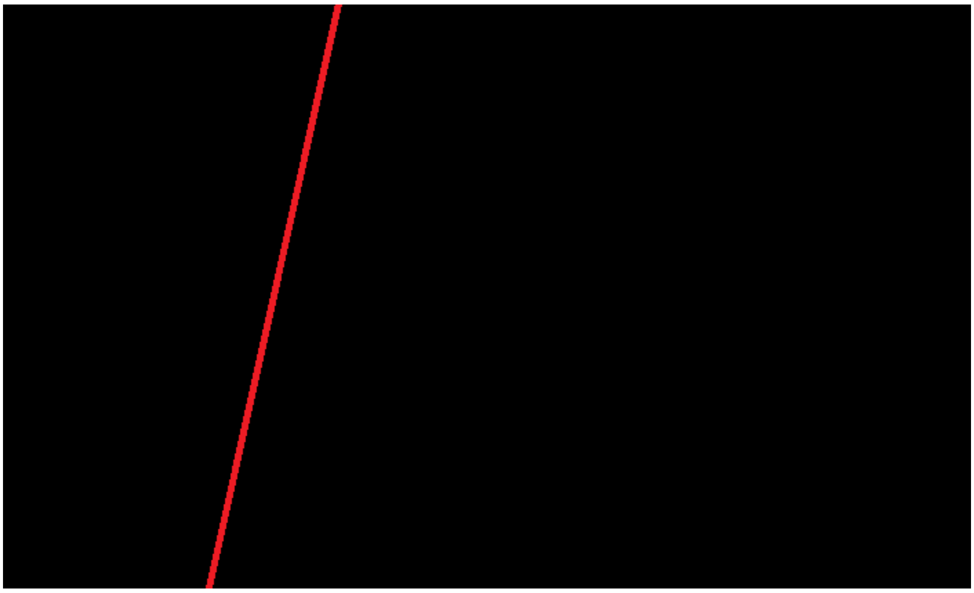
Example image - highlighted lines

After that whole lines are created using the pattern recorded.



Example image - red lines

This image is then compared to a predefined image to calculate the relative position to these lines and the movement needed to improve it (we want to stay a constant distance from the nearest line on the left).



Example image - base image

The difference is calculated as an angle, by rotating and moving the image to fit the base image (approximately).

3.8.2 Communication protocol

As was mentioned above, the result of the image processing is an information about the direction change needed to improve the position of the vehicle. According to the rotation, the angle used is sent to the control unit, where the front of the vehicle is equal to 0°.

Frame structure

Angle of direction change
x

Where x belongs from –60° to 60°.

3.8.3 Road signs camera (To be reviewed)

This camera is taking pictures of the road surroundings, namely the area to the right of the road, to record any road signs. The images should be in good quality to be able to perform a correct analysis. That might delay the framerate of the processing, however that is not a problem in this case. The motherboard to which the camera is connected then compares these images with a stored list of road signs (image recognition). When it finds a match, it sends the recognized road sign as an **integer** to the device in charge of control. This also means that the control device has to have a custom list of these road signs (in number form) with special behavior for each of them.

Frame structure

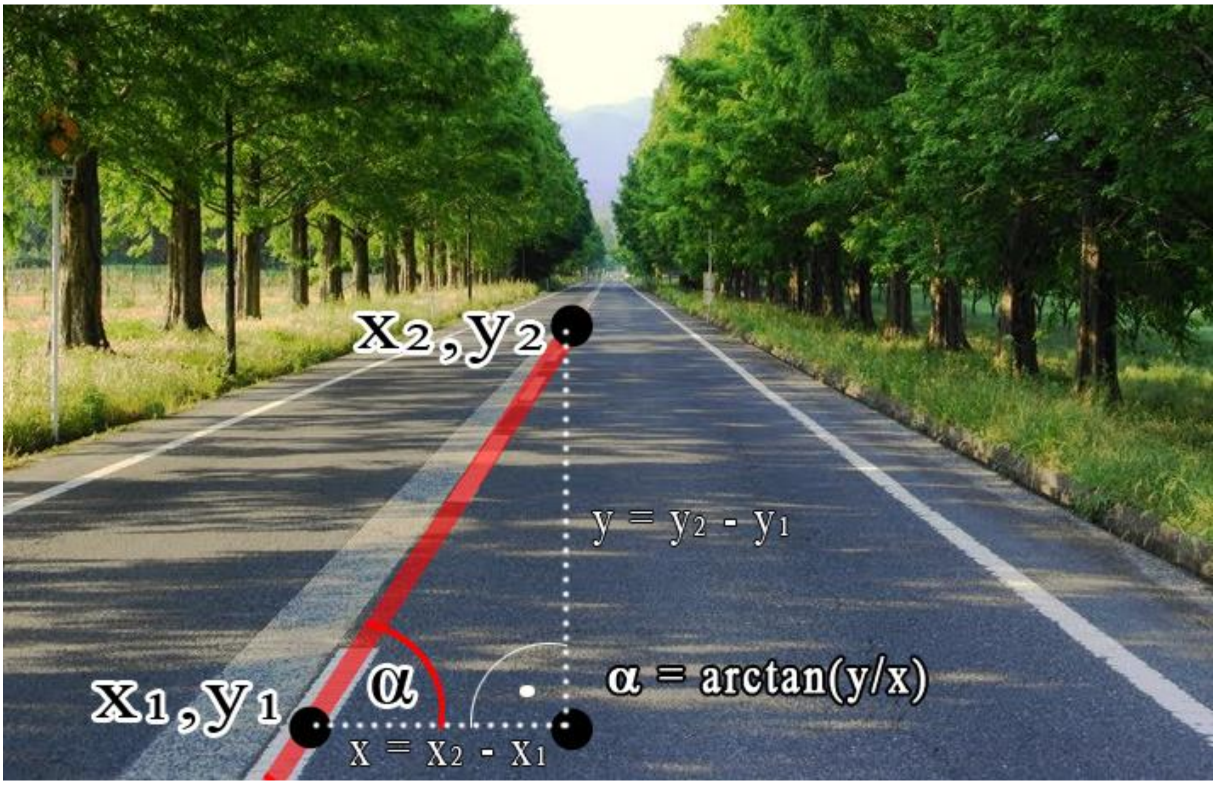
Number of road signs	Road sign x1	Road sign x2	Road sign xn
n	#1	#2	#n

3.9 Angle measuring

After recognition guide line, there is necessary to measure angle of that line. This information is needed for specifying next move. Only two points are enough to measure angle of that line. Specifically, both points are given by their coordinates (location on horizontal line and location on vertical line). So, one point in 2D space is given by *x* (horizontal) and *y* (vertical).

As there are needed only two points, computation includes four values. These two points create right triangle. Thus, by using trigonometric functions it is possible to count angle between two points. In this case, it is used tangent equation. Since the angle must be count, inverse function is used (arcus tangent).

The principle is shown in next figure:



Principle of angle measuring

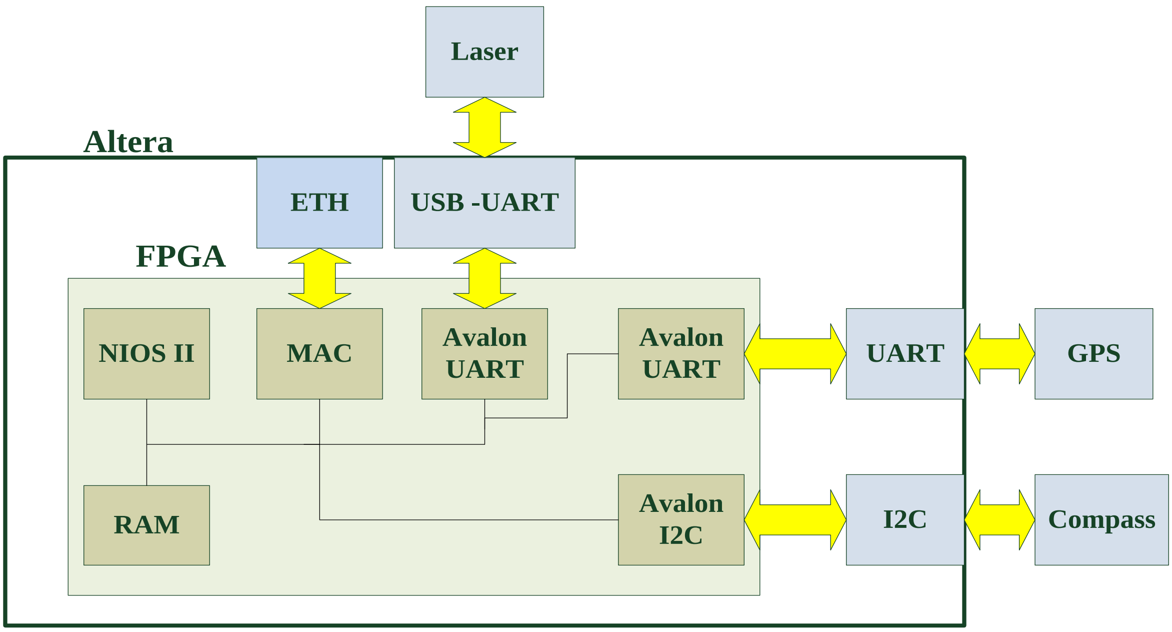
It is possible to do in OpenCV library. This library offers interface for C programming language.

4. IMPLEMENTATION

4.1 Altera FPGA realization

FPGA will be programmed to contain IP cores shown on picture below. It will allow communication with all three sensors via UART and I^2C protocol. Cores are made in Altera Quartus Prime program using QSys tool.

- NIOS II – free version of 32-bit embedded-processor architecture designed for smallest possible logic utilization of FPGAs. Contains JTAG debug module and up to 256 custom instructions. Acts as avalon mm master.
- RAM – random access memory. Acts as avalon mm slave.
- MAC - is IP core for communication with ethernet interface with deterministic ethernet support from TTTech. Acts as avalon mm slave.
- AVALON UART - The UART core with Avalon interface implements a method to communicate serial character streams between an embedded system on an Altera FPGA and an external device which is in our case Laser and GPS. Acts as avalon mm slave.
- AVALON I2C - simple two-wire, bidirectional interface developed for I2C communication with any I2C slave device with compatible pins in our case with compass. Acts as avalon mm slave.



Realization of FPGA

4.2 GPS prototype

GPS prototype is written in C and has functions for GPS navigation. Map is represented as array of structures, where structure describes one point on the map.

Implemented functions are:

Is_in_node(nav_point actual,nav_point dest) – determines if actual point is in defined range of destination point. Defined range is slightly more than accuracy of GPS.

calculate_compass_degree(nav_point start,nav_point end) - Function to calculate degree between two nodes

find_closest_point(double longitude,double latitude) – finds closest node to actual position

degree_based_on_quadrant(double x,double y,double degree) - Function for degree calculation based on quadrant

4.3 Control Unit prototype

Prototype of control unit is written in Python. It consists of the following modules:

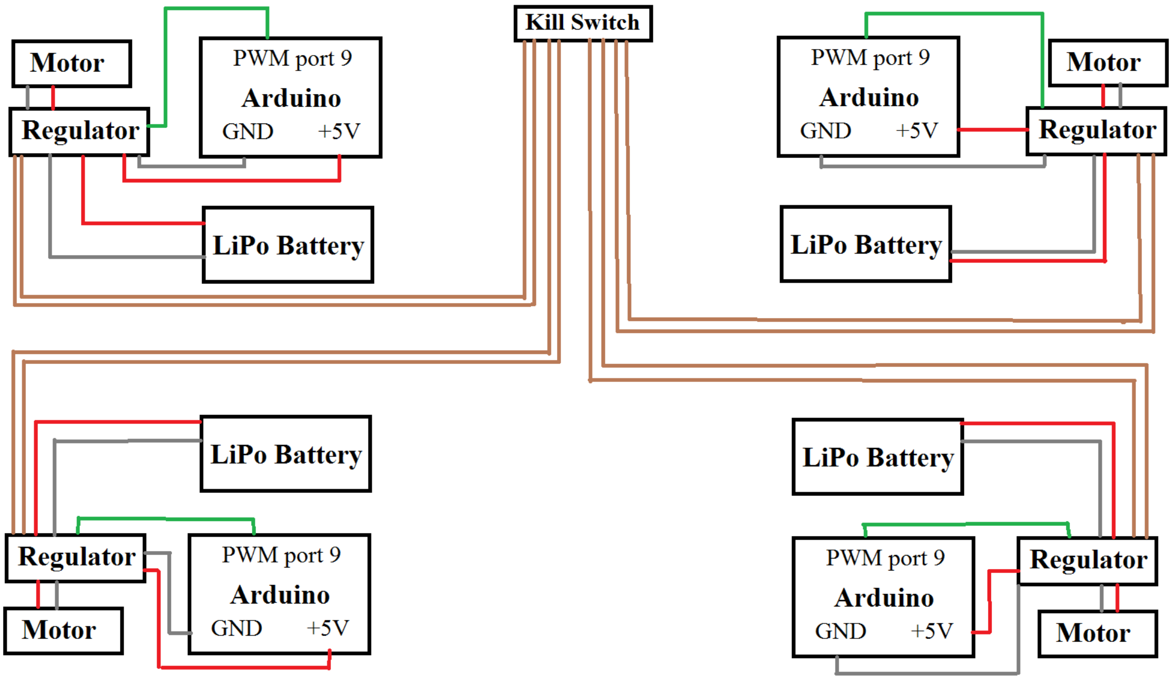
- Compass.py
- Gps.py
- Laser.py
- Controlunit.py
- Parse.py

Compass, GPS and Laser represents modules for storing data from these sensors and also methods to work with them.

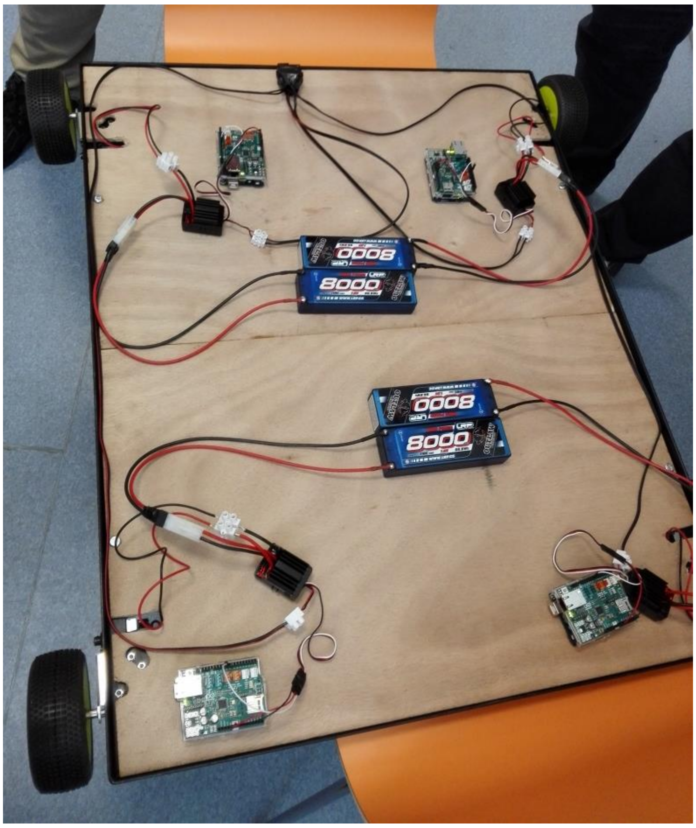
Control unit contains 2 main threads. One thread is responsible for receiving packets and updating data in sensors objects. Second thread makes control decisions.

4.4 Car wiring

In the picture below is shown wiring diagram which describes how cables and devices are connected within the car. Every Arduino use 3 wires to connect to regulator. First cable is +5V (red), second cable is ground (grey) and third cable is PWM signal which controls a motor movement. Every regulator is connected to its battery which provides a power supply for an Arduino and a motor. There is also a kill switch in case of emergency. Kill switch switches of every regulator in the car so the car will stop immediately after a kill switch was pressed.



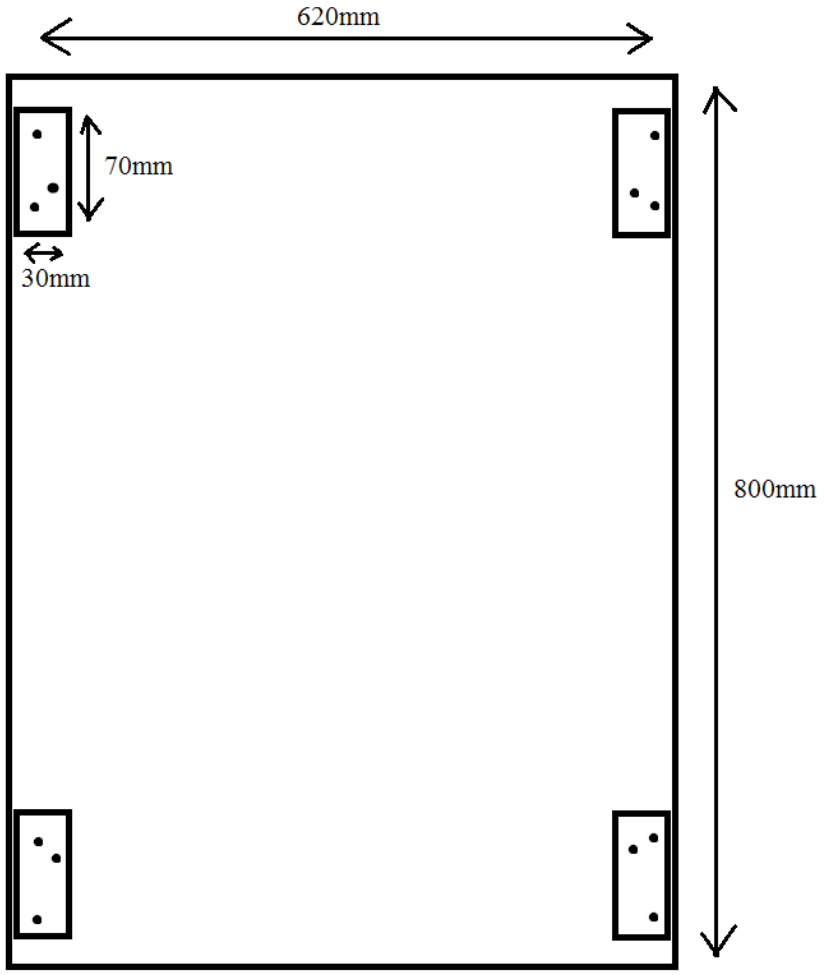
Wiring diagram of an autonomous car



Wiring of real vehicle

4.5 Car construction

A car construction can be seen in the picture below. A basic rectangle is made of L - shaped metal with dimensions 20x20mm. It is welded in every corner. Four small platforms were placed inside the main rectangle to hold motors with transmissions. Every platform has 3 drilled holes with 3mm diameter. These holes are used to mount motor to platform. Platforms are also welded to main rectangle. Inside the rectangle there is a wooden surface which is used to store every device used in the car. The whole car weights around 7 kilograms.



Car construction scheme

4.6 Laser data processing

Processing of laser data is also written in C programming language. This section of implementation includes implemented simple function:

int[] evaluate_data(int laser_data[numAngles])

This function evaluates each angle from input array and based on this, it creates output array for control unit.

As input parameter in this function, it is array of angles from specific measurement. Function is constructed dynamical and if there is need to evaluate less number of angles, only variable *numAngles* must be changed.

Output array includes information about open ranges of angles (with enough space to pass through) and their number. Detailed description is in the section 3.4.

Nature of algorithm is based on loop, in which each range is evaluating (regarding previous angles). If distance at a given angle is less than limited distance, range is closed and added to the output array.

4.7 Image processing for road lines detection

Image processing is written in Python language using the Open CV library. The implementation includes loading an image, converting it to a greyscale image. Then thresholding the image to create a binary image consisting of black and white points. Thresholded image is then processed with canny algorithm to detect edges of objects and after that Hough transform algorithm is used to detect straight lines and those are written into a new image.

Road lines detection

5. EXPERIMENTS

5.1 Vehicle construction

After constructing a vehicle, several tests have been made. These tests were aim to check if vehicle had been constructed properly. We checked cabling, correct soldering by measuring the voltage. We connected batteries to motors with regulators and checked its functionality. In next step, we connected Arduino boards and checked if they are powered. To sum it up, testing vehicle construction and powering was successful.

5.2 Vehicle movement

After we constructed vehicle, we tested its movement. This test was performed indoors. First time we tested vehicle movement in our lab, where we it was constructed. There were two types of tests:

- straight movement,
- turning.

Purpose of straight movement test was to prove that vehicle is able to go straight without human control. This test was successful, despite its high noise. Unfortunately, there is no way we can fix high noise.

Turning test was held in the hallway. The purpose of this test was to prove that vehicle is able to turn. This test was also successful. Thanks to our software implementation and vehicle construction, vehicle was able to turn almost on the spot.

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