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Application of deterministic Ethernet for distributed embedded systems

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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 section 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.

2. ANALYSIS

This section contains analysis of components which some of them are part of autonomous car. Components are devided 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.

The smallest and most common form of antenna is the 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.

Some GPS modules use helical antennas.

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.

Some modules can be used 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.

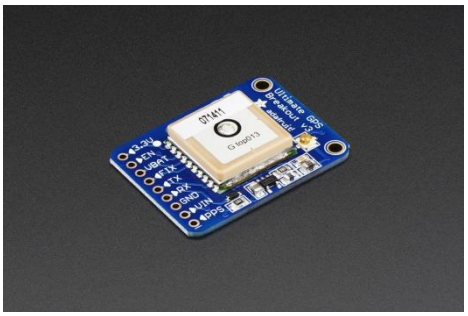
TTFF - Time to first fix. The time it takes, after power-on, to accurately compute your position and time using at least 4 satellites. If you are in a location with a bad view of the sky, the TTFF can be very long.

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 Rasperry 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



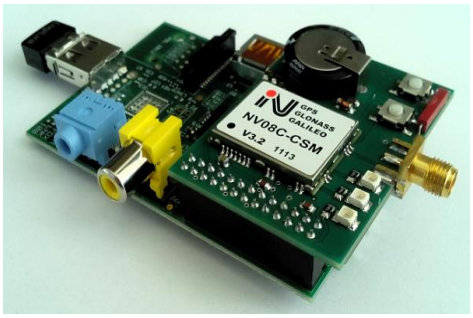
This module has detailed step by step guide for arduino and raspberry pi boards and that is the main reason we have chosen this GPS module. It offers very good specifications according to its price.

It support also DGPPS, WAAS, EGNOS, jammer detection and reduction and multi-path detection and compensation. Output of this module is in standart 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

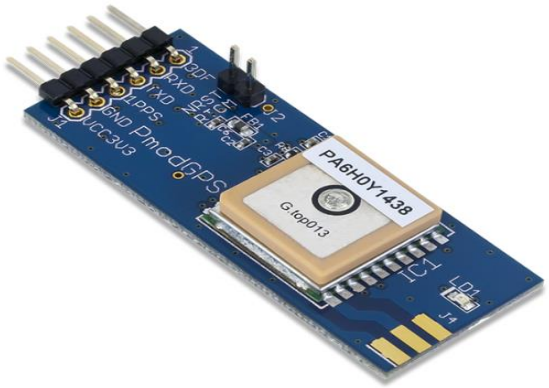
This module was tested for compatibility with raspberry pi 3 B and has updated instalation guide according to it. For 170 euro it is not very much better then the previous Adafruit ultimate GPS breakout.



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 meter 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.



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

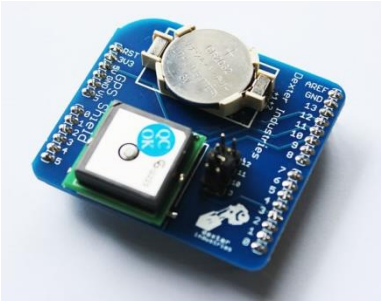
Using the standard NMEA protocol to provide information like speed, position and altitude, the GPS shield works great both inside and outside. It is available at a price of €82.00 and enables the data via serial port.

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

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.

- **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, theenvironmental temperature and the operating durationare not influenced easily to the distance detection because of adopting the triangulation method. This device outputs the voltage corresponding to thedetection distance. So this sensor can also be used as a proximity sensor. It is also suitable for robot appliactions.

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 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 smarphone, 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.

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.

2.3.3 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.

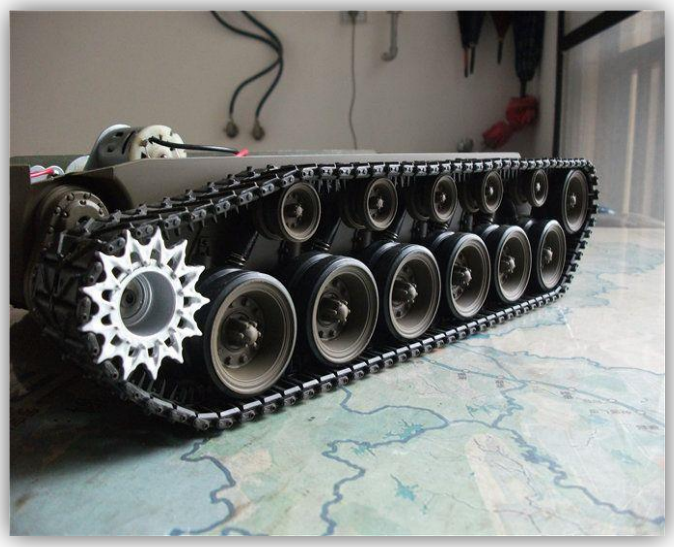
2.4 CAR PLATFORMS

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)

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

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

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

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

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 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 not 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 at least 800x900 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 senzor 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 Fixed 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.

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 surveilance 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.

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€

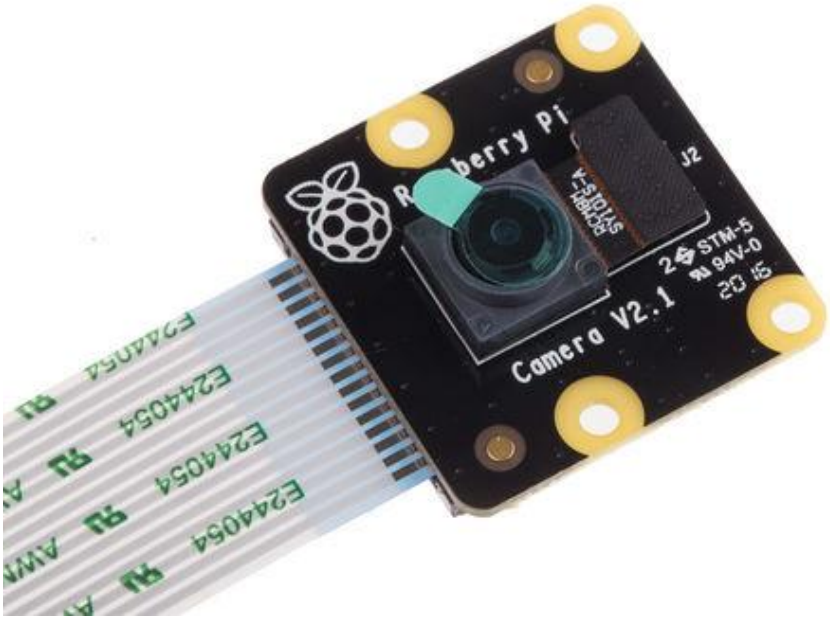
This camera module is made specifically for the raspberry Pi motherboard. Provides high definition images/footage. With it's really tiny size it can fit anywhere, it has practically no weight at all. Camera accessible using libraries, eg. Picamera. Does not have infrared vision.

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.


Camera V2.1

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

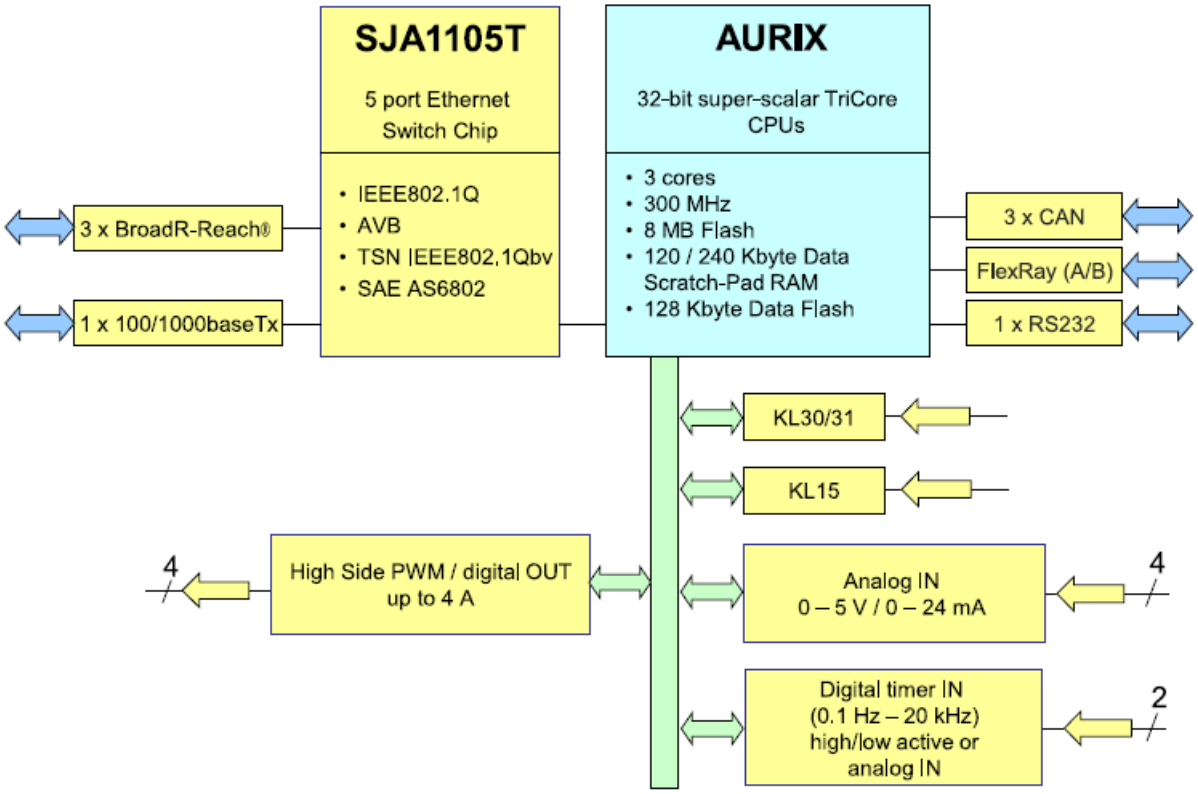
- **IEEE 802.1D™**-2004 (layer 2 switching)
- **IEEE 802.1Q™**-2011 (VLAN support)
- QoS handling based on IEEE 802.1Q PCP bits
- Support for SR Class A, Class B and Class C traffic
- **IEEE 802.1AS™**-2004 (Timing and Synchronization for Time-Sensitive Applications in Bridged Local Area Networks)
- **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 toplogy.

3. SOLUTION DESIGN

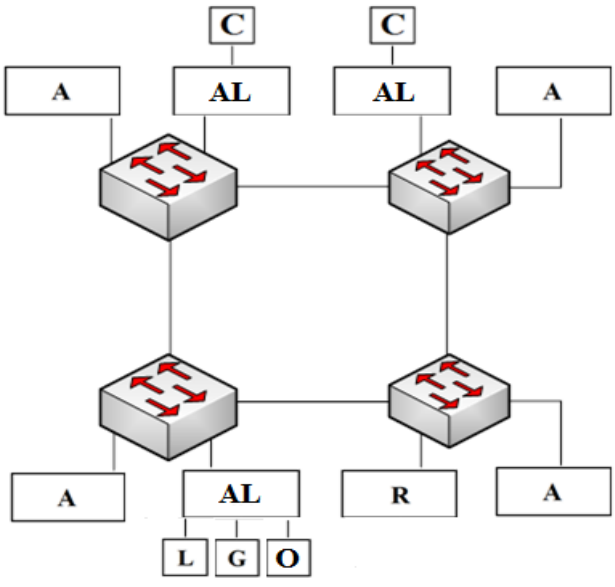
3.1 Logical design

Logical design of car can be seen 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 we will need ethernet shields, because arduinos do not have ethernet port by default. Raspberry Pi will send signals to control the speed of each wheel.

Raspbery Pi will act as central point and other boards with sensors will send control infrormations 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. And for car navigation we will use GPS sensor. Navigation with GPS is described in section 3.3.



Logical design of car model

3.2 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 no. 1 below.

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

Screen no. 1 Communication protocol

3.2.1 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

Screen no. 2 Type field

3.2.2 Source board field

Source board field i sused 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

Screen no. 3 Source board field

3.2.3 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

Screen no. 4 Number of source board field

3.2.4 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

Screen no. 5 Destination board field

3.2.5 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

Screen no. 6 Number of destination board field

3.2.6 Type of message field

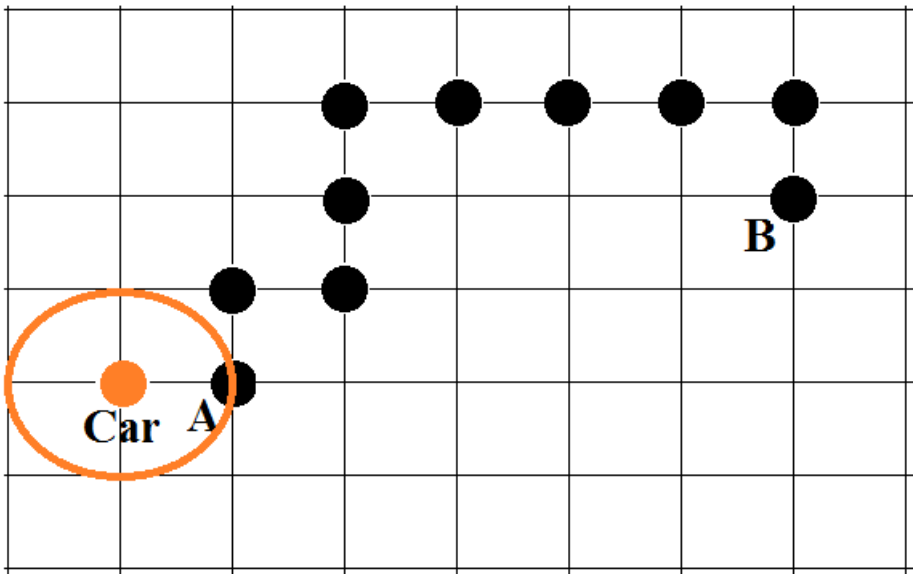
Message can have different meaning. Value 0 represents notifying of IP address. This type of message is send when IP address is assigned to inform central board. Value 1 stands for instruction from central board to others. Value 2 defines message which servers for acknowledgment of received instruction.

TYPE OF MESSAGE	notifying IP address	instruction	instruction ACK
IDENTIFICATOR	0x00	0x01	0x02

Screen no. 7 Type of message field

3.3 Navigation with GPS

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

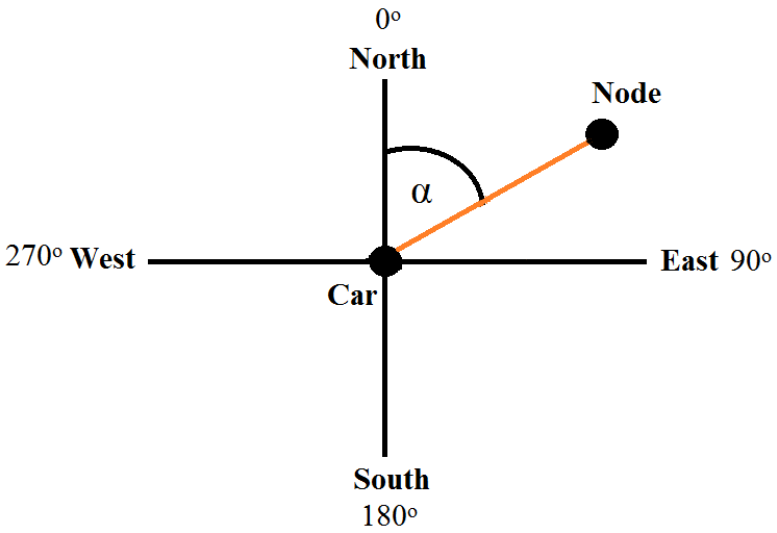


Simplified navigation map

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 based on OpenStreet maps will be used to compute the best path.

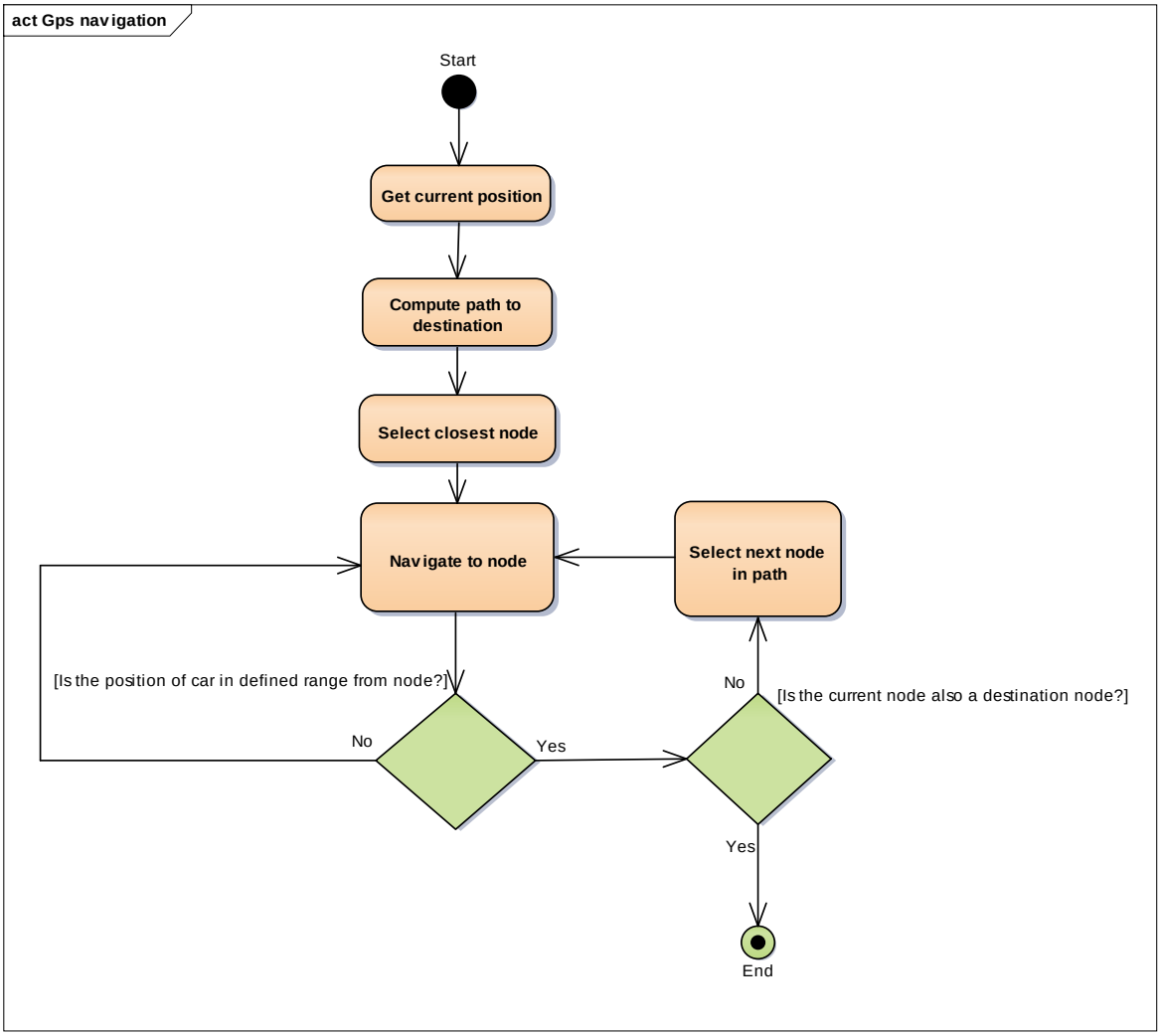
After the path is known, the navigation process begins. Every place in the world can be defined with latitude and longtitude. The precision of GPS sensor is around 5 meters, therefore we can only approximately tell where our vehicle is. Defined path will be represented by nodes on the real road. Distance between these nodes must be greater then 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 can not accuratly 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.



Calculating 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.

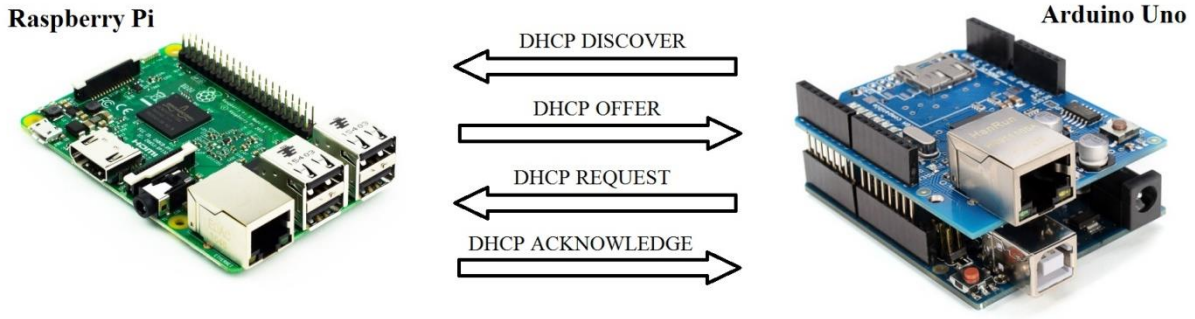


Activity diagram of GPS navigation

3.4 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 Rraspberry 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.



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 recognise which Arduino controlls which motor. For example, number 1 means that it is an Arduino which controlls 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.

4. IMPLEMENTATION

5. EXPERIMENTS

6. CONCLUSION

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