

**PROJECT TITLE:** TMS320F28335 Based Main Board for an Autonomous Model Car

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**UNIVERSITY:** University of Applied Sciences Zwickau

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**TI PARTS USED IN PROJECT:**

- 1 x TPS54620 (<http://focus.ti.com/docs/prod/folders/print/tps54620.html>)
- 1 x TPS62111 (<http://focus.ti.com/docs/prod/folders/print/tps62111.html>)
- 1 x TPS62112 (<http://focus.ti.com/docs/prod/folders/print/tps62112.html>)
- 1 x TPS62400 (<http://focus.ti.com/docs/prod/folders/print/tps62400.html>)
- 1 x TPS3306-18 (<http://focus.ti.com/docs/prod/folders/print/tps3306-18.html>)
- 1 x TMS320F28335 (<http://focus.ti.com/docs/prod/folders/print/tms320f28335.html>)
- 1 x TLV2464 (<http://focus.ti.com/docs/prod/folders/print/tlv2464.html>)
- 1 x MAX3221 (<http://focus.ti.com/docs/prod/folders/print/max3221.html>)
- 1 x SN65HVD230 (<http://focus.ti.com/docs/prod/folders/print/sn65hvd230.html>)
- 2 x SN74CBT3251 (<http://focus.ti.com/docs/prod/folders/print/sn74cbt3251.html>)
- 4 x SN74LVC2G17 (<http://focus.ti.com/docs/prod/folders/print/sn74lvc2g17.html>)



**PROJECT ABSTRACT**

In the last years, some contests have been initiated for autonomous model cars. One of these contests is the Carolo-Cup at the TU Braunschweig (Germany). To participate, the students have to develop a model car which is able to drive autonomously on a model race course, to detect crossroads, to bypass traffic obstacles on the road and to perform an automatic parallel parking procedure. For

such a model car, besides a high-quality chassis, an electronic control unit is needed. The tasks of this control unit are the sampling of various sensor data and the control of actuators for driving and steering. This report describes the implementation of a microcontroller-based main board for an autonomous model car. The microcontroller used in this project is the TMS320F28335 from Texas Instruments.

## **1 Introduction**

The importance of driver assistance systems has increased over the last years. Therefore, students of the University of Applied Sciences Zwickau formed the team S.A.D.I. (Students' Autonomous Drive Initiative). The goal of the team is to develop and implement autonomous model cars on the scale 1:10. A true challenge is the implementation of the best possible vehicle guidance in different scenarios.

The model car shall be able to drive autonomously on a model race course, to detect crossroads, to bypass traffic obstacles on the road and to perform an automatic parallel parking procedure. In contrast to many other known industrial solutions, the car should complete these tasks at a relatively high speed (up to 15 km/h) and at a high accuracy of measurement.

The chassis of a high-quality racing model car provides the basis for the autonomous model car. To fulfill all requirements, the car is equipped with ultrasonic sensors, a rotary encoder and a CMOS image sensor. A DC motor and a servo-motor unit are used for driving and steering. A remote control unit allows selecting one of the predefined drive tasks and to modify certain control parameters of the embedded software. A LCD is used to visualize a menu and further information. A MCU-based board evaluates the sensor data, calculates new control values by a digital PID algorithm and drives the corresponding actuator. The communication with the sensor system is performed by different interfaces, such as CAN, I2C, SPI or SCI.

## **2 Motivation for Project**

One of the major motivations for the project was the further development of the current model car. The features of two boards had to be improved and combined on one board. The new main board will minimize the costs and improve the energy consumption. Furthermore, the project offered the opportunity to gain practical experience in both software and hardware development.

### 3 Implementation

#### 3.1 Schematics and Board Layout Design

The board is divided in two main areas, the power section and the electronic section. The power section is used to control the DC motor and the servo-motor. It contains the load power supply and the H-bridge motor driver. The electronic section contains its own power supply as well as digital and analog parts of the circuit. The layout was implemented in four layers. The outer layers are used as signal layers. The inner layers are used as ground plane and as power plane. Both planes are split into several areas based on the component placement. Figure 1 shows the splitting of the ground plane. The splitting of the power plane is identical, but without the connecting paths. All supply-positive pins of the MCU and other ICs are equipped with bypass capacitors. They are placed near the respective pins, without using any via.

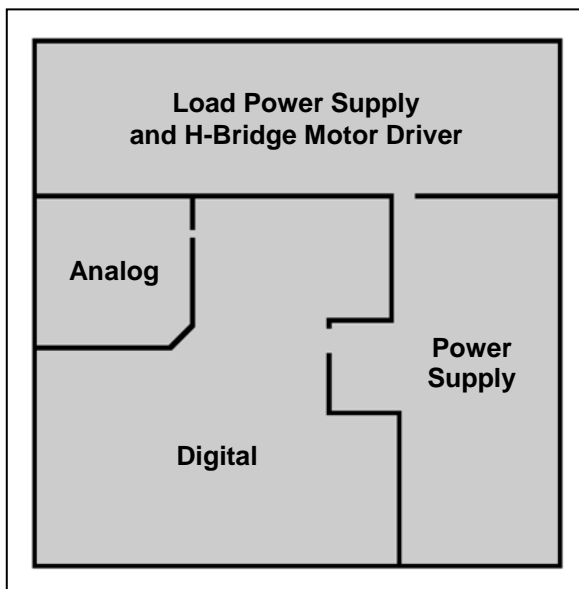
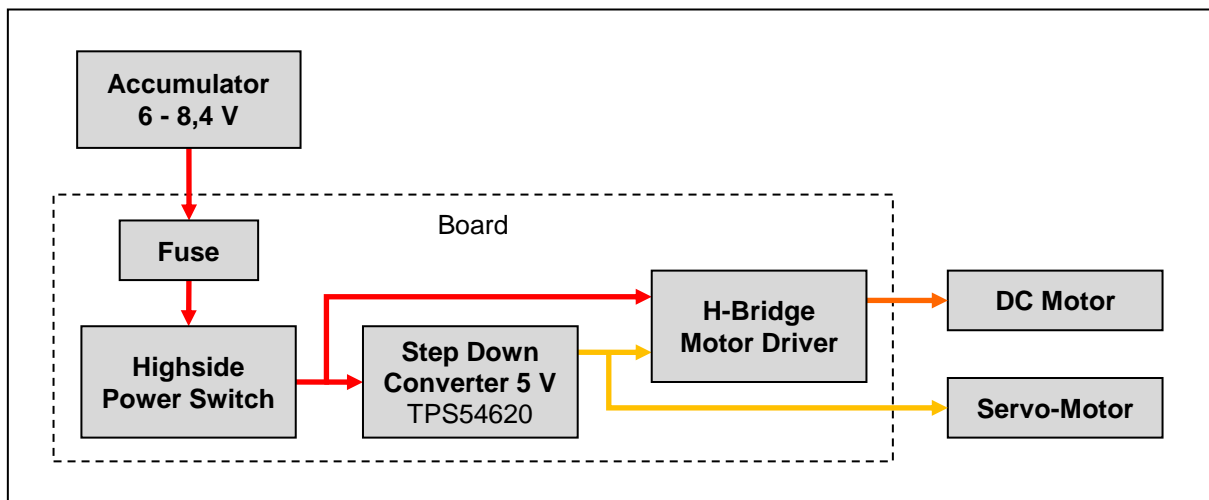


Figure 1 Splitting of the Ground Plane

### 3.2 Power Supply

The power supply will be provided by two separate accumulators, one for the high current (DC motor and servo-motor) and the other one for the electronic control of the car. Each power supply is fused and equipped with a highside power switch.

Figure 2 shows a block diagram for the power section of the board. To provide the supply voltage for the servo-motor and the H-bridge motor driver, a step down converter is used. The maximum current consumption of the servo-motor and the H-bridge motor driver is approx. 4.5 A. The chosen step down converter TPS54620 can drive a maximum current of 6 A. For the calculation of the LC low pass filter and other additional components the TI online design software SwitcherPro™ was used.



Advantages of the TPS54620:

- design software SwitcherPro™ makes it easier to calculate all components
- provides supply voltage of 5 volts and an output current of up to 6 ampere
- adjustable undervoltage lockout prevents deep discharge of the accumulator
- frequency compensation
- high efficiency
- small dimensions
- output overvoltage protection, overcurrent Protection, thermal shutdown

The power supply of the electronic section consists of three step-down converters. The corresponding block diagram is shown in Figure 3. To supply external components (sensors, LCD, RC receiver) over a pin contact strip, output voltages of

**Figure 2 Block Diagram for the Power Section**

3.3 V and 5 V are needed. The TPS62111 and the TPS62112 provide these output voltages. Each one can drive an output current of up to 1.5 A. Because the fixed output voltages can be used, less additional components are needed. The output voltage of 5 V from the TPS62112 is also used for the third step-down converter. The TPS62400 provides the supply voltage of 3.3 V for all onboard components and the core voltage of 1.9 V for the MCU. Its output currents are up to 400 mA for the first output and up to 600 mA for the second. Additionally, the supervisory circuit TPS3306-18 is used to monitor the nominal supply voltages. It also ensures proper system reset with a delay time of 100 ms.

As the analog circuitry is small compared to the digital parts, the analog supply is generated from the digital supply. To isolate the analog supply from the noisy digital supply rail, passive low pass filters with ferrite beads (instead of standard inductors) are used.

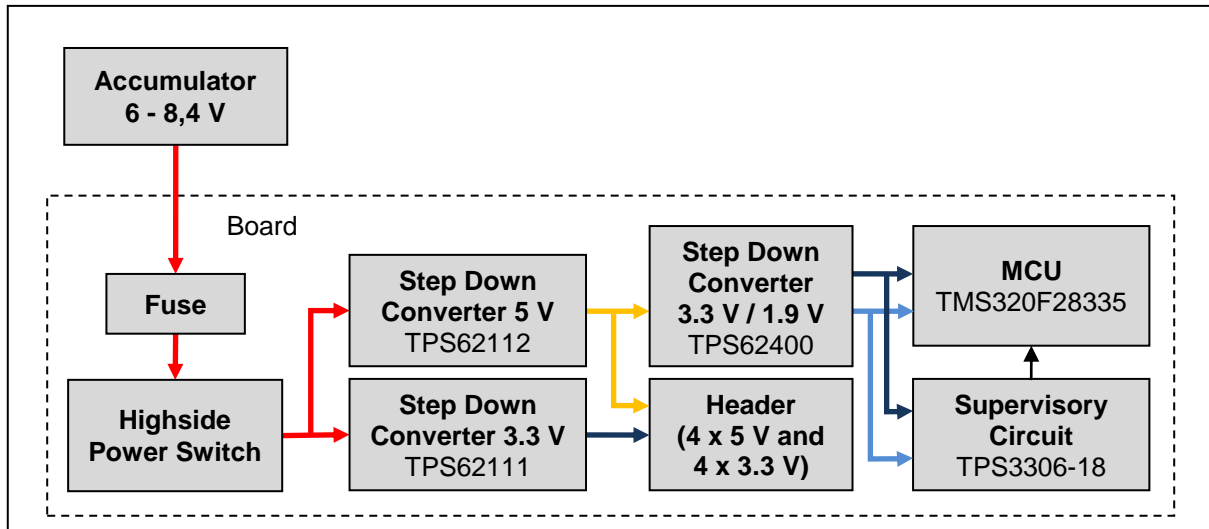


Figure 3 Block Diagram for the Electronic Section

Advantages of the TPS62111 / TPS62112:

- provides supply voltage (fixed output voltage can be used) of 3.3 V / 5 V and an output current of up to 1.5 A
- high efficiency
- small dimensions
- low-battery detector to save the accumulator
- overtemperature and overcurrent protection

Advantages of the TPS64200:

- provides both supply voltages needed for the MCU
- high efficiency
- small dimensions
- allows the use of small inductors and capacitors

Advantages of the TPS3306-18:

- designed for circuit initialization which require two supply voltages
- ensures proper system reset with a delay time of 100 ms
- small dimensions

### 3.3 Electronic Control

The electronic control section is based on a microcontroller. The TMS320F28335 combines control peripheral integration with the processing power of a 32-bit architecture. The integrated peripherals reduce the complexity of the embedded software and save computational power. The internal flash memory allows storing the control code in non-volatile memory without adding external components.

Advantages of the TMS320F28335:

- integrated peripherals reduce the complexity of the embedded software and save computational power
- ePWM is used to control the H-bridge motor driver and the servo-motor
- eCAP is used to measure the pulse width of four channels of the RC receiver
- eQEP is used with a rotary encoder to measure the motor speed
- ADC is used to measure the motor current
- eCAN is used to communicate with other MCU based boards
- SCI is used to communicate with a PC
- SPI is used for a LCD and an EEPROM
- I2C is used to communicate with sensors (e.g. ultrasonic sensor)
- 150 MHz CPU clock rate enables short processing time
- embedded flash memory with special memory pipelining to achieve higher performance

#### Control of the DC Motor and the Servo-Motor:

To control the H-bridge motor driver, a PWM signal (0-100 %, 20 kHz) is used to adjust the amplitude of the motor voltage. The motor polarity can be switched using two GPIOs. Another PWM signal (1-2 ms, 61 Hz) controls the servo-motor.

#### Evaluation of up to four Channels from an RC Receiver:

Connecting an RC receiver to the board allows manual control of the model car, intervention during an autonomous drive, selection of subroutines and the modification of parameters. Up to four channels can be connected and evaluated. On each channel, the pulse width of a PWM signal (1-2 ms, approx. 50 Hz) can be measured using capture inputs of the MCU. Two dual Schmitt-trigger buffers SN74LVC2G17 are used to accept input voltages up to 5.5 V and to transform slowly changing input signals into sharply defined signals.

Advantages of the SN74LVC2G17 Dual Schmitt-Trigger Buffer

- accepts Input voltages up to 5.5 V
- sharply defined signals
- low power consumption
- ESD protection

#### Measurement of Motor Current and Accumulator Voltage:

The ADC enables to measure the accumulator voltage and the motor current. The latter is measured across an external resistor on the current sense output of the H-bridge motor driver. The current sense output drives a current proportional to the motor current. Two other ADC inputs are routed to a pin contact strip. Op-amp driver circuits are used for signal conditioning of input analog signals. They provide

low/stable output impedance and protect the ADC inputs. Therefore, the quad operational amplifier TLV2464 is used.

Advantages of the TLV2464 Quad Operational Amplifier

- specifically designed for portable applications
- ideal for buffering analog-to-digital converters (rail-to-rail performance with high-output-drive capability)

#### Communication with Other Boards:

The CAN interface enables the communication with other boards (e.g. camera board) on the model car. The used CAN transceiver SN65HVD230D provides differential transmit capability to the bus and differential receive capability to the CAN controller at speeds of up to 1 Mbps.

Advantages of the SN65HVD230 CAN Transceiver

- for signaling rates of up to 1 Megabit/Second
- low power consumption
- ESD protection

#### Communication with a PC:

The RS-232 interface enables the communication with a PC. This feature can be used to transfer stored sensor data and analyze them on a PC. The used RS-232 line driver/receiver MAX3221 provides the electrical interface between an asynchronous communication controller and the serial-port connector.

Advantages of the MAX3221 RS-232 Line Driver/Receiver

- operate at data signaling rates of up to 250 kbit/s
- low power consumption
- ESD protection

#### Control of the Ultrasonic Sensors:

Ultrasonic sensors can be used to measure distances to obstacles and indirectly the length of a parking space. The Ultrasonic sensors can be controlled by I2C. Alternatively, it is possible to start the measurement of a sensor with a trigger pulse and measure the pulse width of the echo pulse. The pulse width is measured using a capture input of the MCU. The 1-of-8 multiplexer/demultiplexer SN74CBT3251 is used to connect up to six ultrasonic sensors. The dual Schmitt-trigger buffer SN74LVC2G17 is used to accept input voltages up to 5.5 V.

Advantages of the SN74CBT3251 1-of-8 FET Multiplexer/Demultiplexer

- TTL compatible
- minimal propagation delay
- small dimensions

### Measurement of the Motor Speed:

A contactless magnetic rotary encoder with a resolution of 1024 positions per revolution is used to measure the motor speed. The enhanced quadrature encoder pulse (eQEP) module is used for direct interface with the rotary encoder.

### Control of the LCD:

A LCD can be controlled by SPI to visualize a menu and further information.

### External Memory:

An EEPROM with a storage capacity of 1 KB allows storing model car depending parameters independent of the control code. The communication with the EEPROM is performed through SPI.

### Start Button and LEDs:

As the rules of the Carolo-Cup include a start button as well as LEDs for direction indicators, brake lights and a signal light, the corresponding circuits and connectors are located on the board. To switch the LEDs, two dual N-Channel field effect transistors are used.

### 3.4 Software Concept

The software concept is based on structured programming. Therefore, the program is divided in several software modules. A module consists of a header file (\*.h) and a C file (\*.c). The header file contains the function declarations with a short description, whereas the C file contains function definitions. This simplifies the integration of software modules in a project. Related code segments are placed in one module. Furthermore, the modules are categorized into target dependent and target independent code. Code segments which are independent from the used hardware are placed in modules with the prefix "ti\_" (target independent). These modules can be ported to other targets without any changes on the code because they do not directly access or modify control or status registers of any on-chip or off-chip peripherals. In contrast, target dependent modules are dependent on the specific MCU. These modules are named with the prefix "td\_" (target dependent). A target dependent software module always contains a function for the initialization of the related hardware registers. Figure 4 shows the software structure of the embedded software. In Table 1 all implemented software modules are listed.

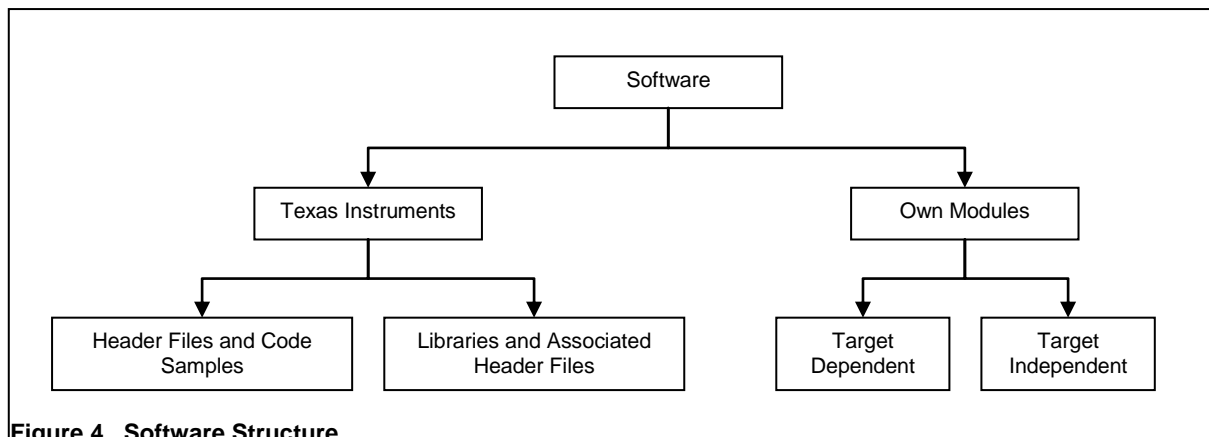


Figure 4 Software Structure

Besides the software modules, there is a special C file named "td\_main.c" which contains the main() function.

The main function consists of the following sections:

- initialization of the system (watchdog, system clocks, flash, CPU timer, interrupts)
- initialization of additional software modules
- enable global interrupts
- delay time until peripherals are ready
- additional initialization (e.g. LCD)
- reading the switch positions of the code switch
- infinite loop (acts as a non-preemptive scheduler)

For the used microcontroller, Texas Instruments provides a collection of header files, code samples and libraries. Parts of this collection are used in this project.

Target Dependent Modules	Target Independent Modules
td_ADC	ti_DriveAutonomous
td_CAN	ti_DriveManual
td_CodeSwitch	ti_Menu
td_Display	ti_Park
td_EEPROM	ti_PID
td_Motor	ti_PID_Lane
td_Parameter	ti_PID_Position
td_RemoteControl	ti_PID_Speed
td_RotaryEncoder	
td_RS232	
td_SignallingSystem	
td_Startup	
td_UltrasonicSensor_CAP	
td_UltrasonicSensor_I2C	

**Table 1 List of Software Modules**

## 4 Conclusions

In this report, the implementation of a microcontroller-based main board for an autonomous model car has been described. For this implementation several ICs from Texas Instruments were used. A special advantage was the excellent support (samples, datasheets, guides, SwitcherPro™, ...) on the website of TI. A software concept for the implementation of the embedded software has been proposed. The software and hardware concepts have been successfully tested on the main board prototype.