µRTE

A modeling framework for safe code on (Multi-Core) Controllers

INTRODUCTION

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Motivation

Hardware/Silicon

Complex Peripherals
Multi-Core
Growing CPU and Memory performance

Software

Powerful hardware enables complex software
Smart Sensor and Actor modules
Complex Libraries
Linker configuration (many memory modules)
RTOS configuration
Change / Fear of refactoring
Lifecycle

Management

Time to market
Development costs
Availability of skilled contributors

Challenges

Especially for
small and medium sized companies

Market Trends

Significant increase in safety related
embedded control systems
Connectivity/IoT

Safety

Safety functions are mostly implemented in software
General trend towards high diagnostic coverage
Freedom from interference (memory, CPU, peripherals)

Qualification

Seamless Documentation
Traceability
Requirement management

Project timeline

Initial idea

Prof. Fromm starts the implementation of a lightweight runtime environment to be used in the academic environment

First industrial contact

Prof. Fromm consults the company Linde who considers to introduce AUTOSAR™ on an AURIX™ multi-core microcontroller for forklift control. After an evaluation phase, an improved version of the lightweight runtime environment is introduced instead.

Thomas Barth joins the research group for his master thesis and starts a PhD program afterwards.

Bundesministerium für Wirtschaft und Energie

HIGHTEC

h_da HOCHSCHULE DARMSTADT UNIVERSITY OF APPLIED SCIENCES

FZI

Public funding

Along with the FZI at the Karlsruhe Institute of Technology and the company HighTec, the research group at Hochschule Darmstadt attracts funding for 2 years to research the applicability of multi-core microcontrollers for safety critical applications.

A feasibility study is conducted in which an possible framework for product development is identified. The development of µRTE starts during this phase.

Industrial evaluation

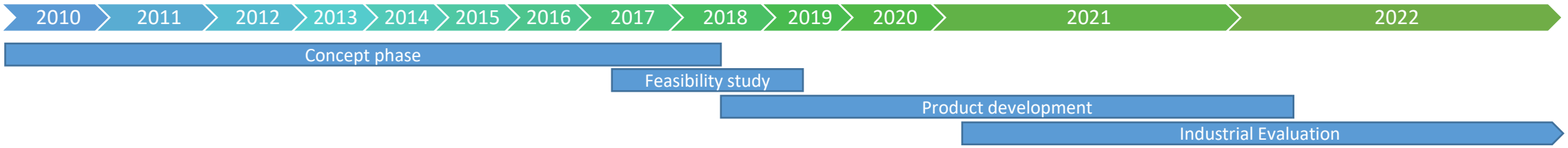
An prototype of µRTE is evaluated in an industrial project in which the software for an safety relevant HMI for an agricultural machine is implemented.

In this project, µRTE is used for software architecture definition, code generation, requirement management and documentation generation.

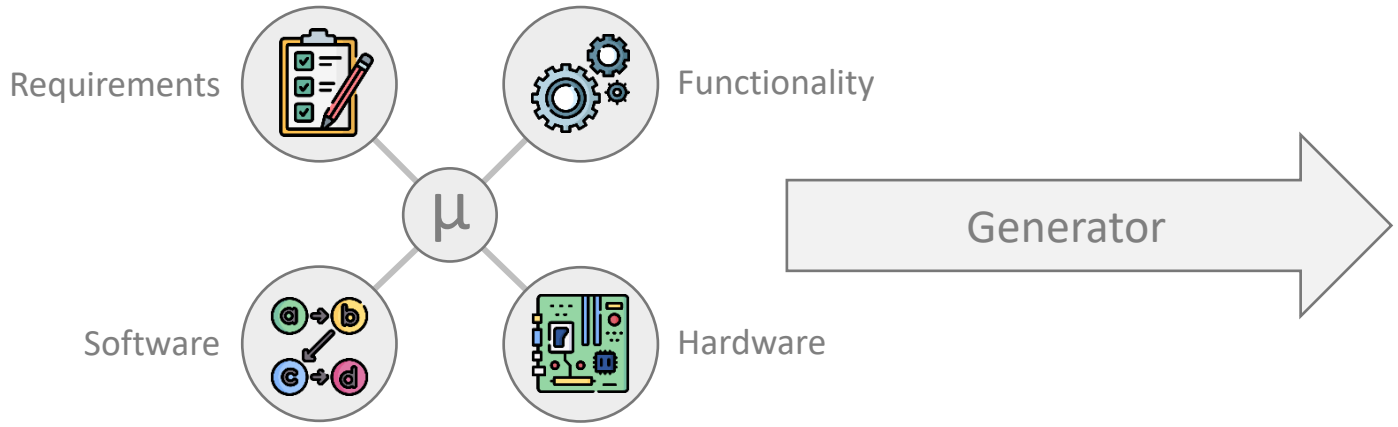
Pre-Release

A first version of µRTE including all core-features is released:

- Software Modeling
- Hardware Modeling
- Functional Modeling
- Requirements Modeling
- Automated model assessment
- Code generation
- Report generation



Scope

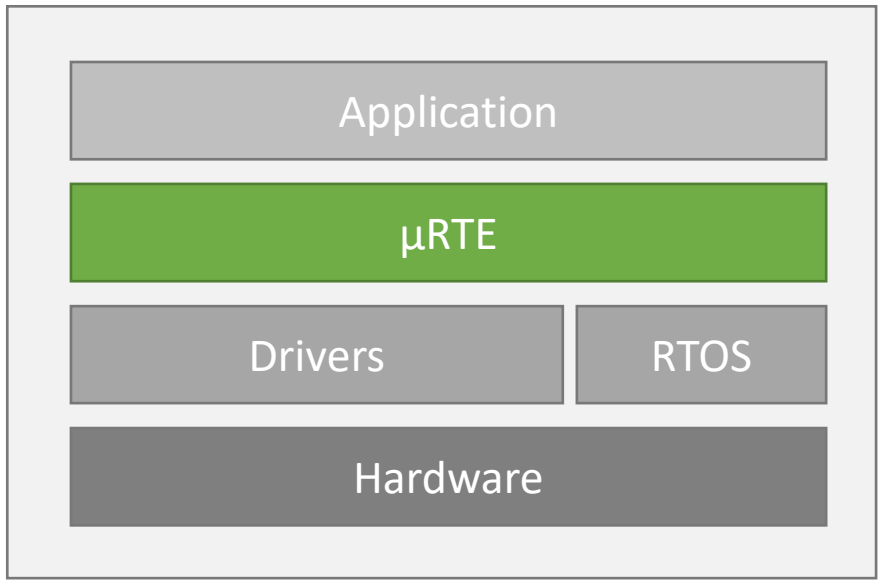


µRTE model

Features

Portability

- Any RTOS
- Any Controller Single/Multi-Core
- Any Toolchain (C/C++ on GCC implemented)



Software features

- Cyclic and Signal driven activation of runnables
- Multiple system-states with own data-flows
- Extensive system and application error handling
- Human readable code

Safety

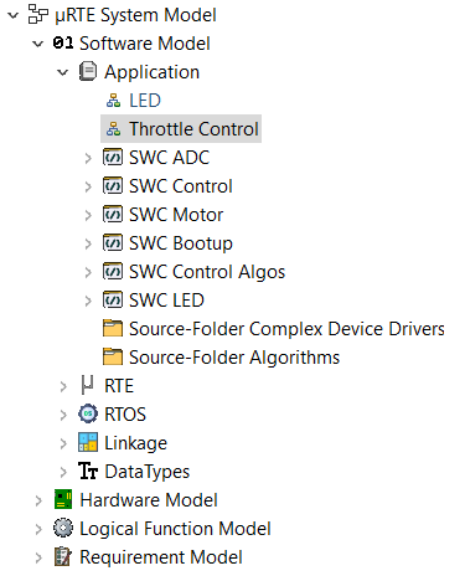
- Complete modeling of the safety case
- Inbuilt consistency and safety checks
- Complete traceability from requirements to implementation units
- Supports freedom from interference
- Generated code complies with MISRA standard

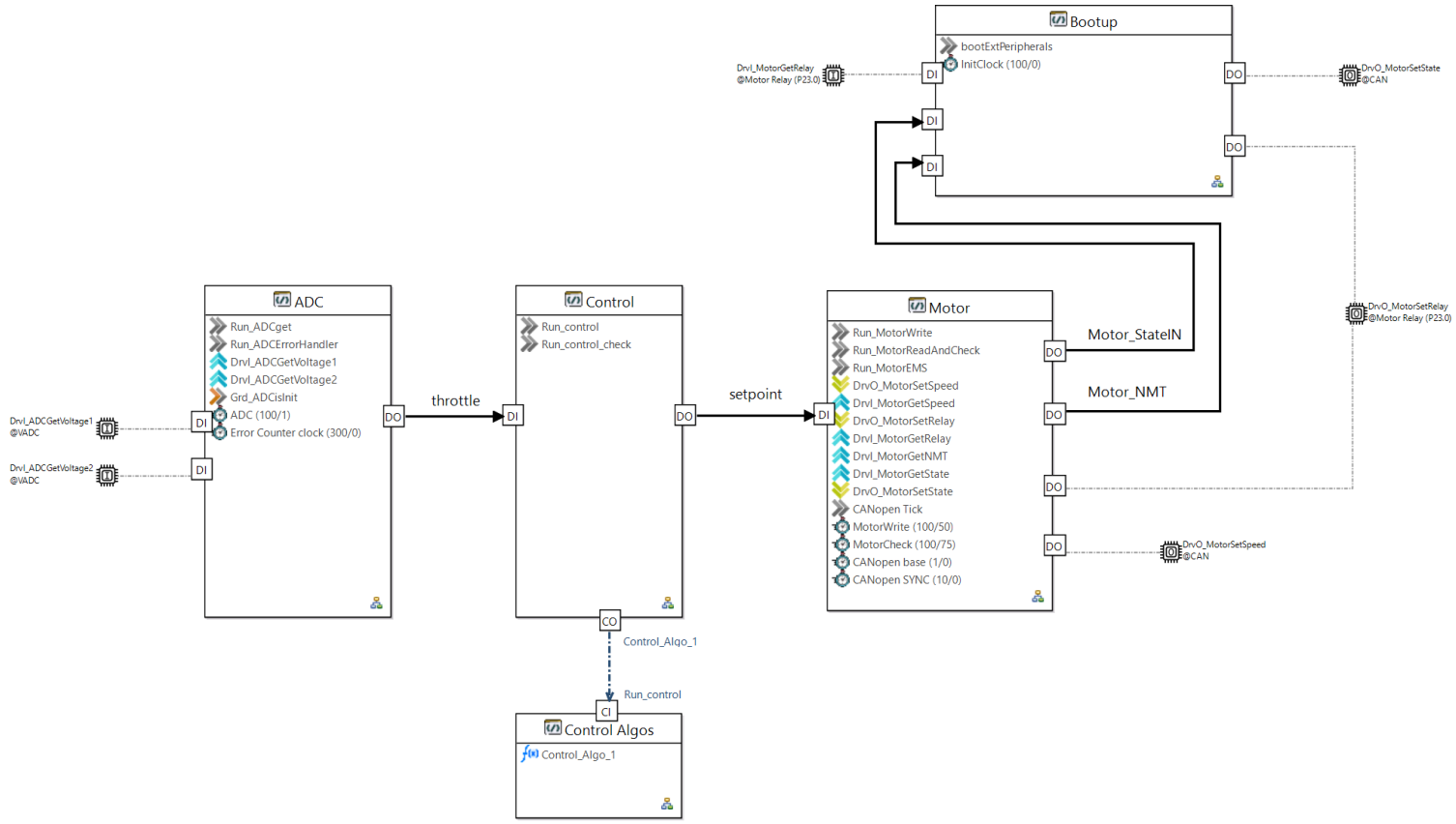
Process

- Encourages clean and modular solutions
- Eclipse plugin implementation
- Intuitive and rich graphical modeling
- Complete support of V-model
- Extensive auto-generated documentation

Software modeling

Each block represents a code file in which software functions are contained
Arrows represent data exchange
Chip-Icons represent hardware interfaces

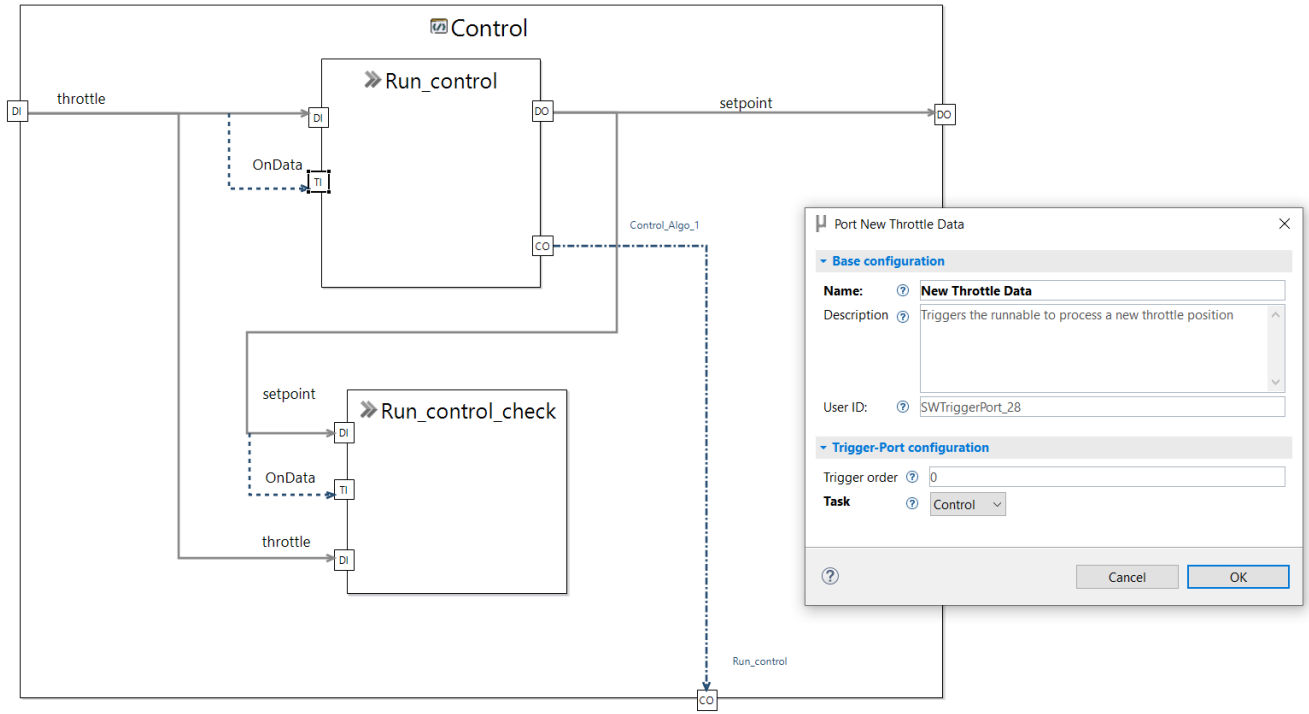




Software modeling

Detailed view describes runnable execution

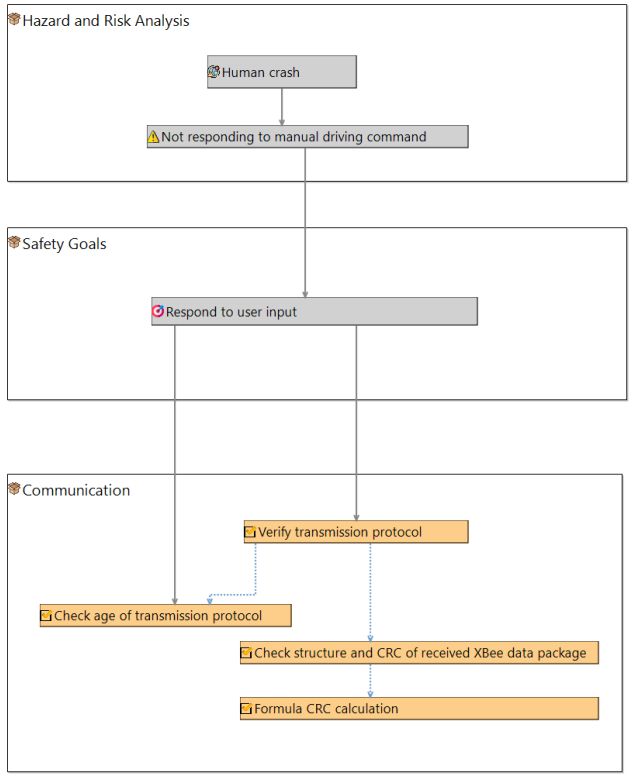
- µRTE System Model
  - Software Model
    - Application
      - LED
      - Throttle Control
      - SWC ADC
      - SWC Control
        - Control
        - Runnable Run_control
        - Runnable Run_control_check
      - SWC Motor
      - SWC Bootup
      - SWC Control Algos
      - SWC LED
      - Source-Folder Complex Device Drivers
      - Source-Folder Algorithms
    - RTE
    - RTOS
    - Linkage
    - DataTypes
  - Hardware Model
  - Logical Function Model
  - Requirement Model



Requirements modeling

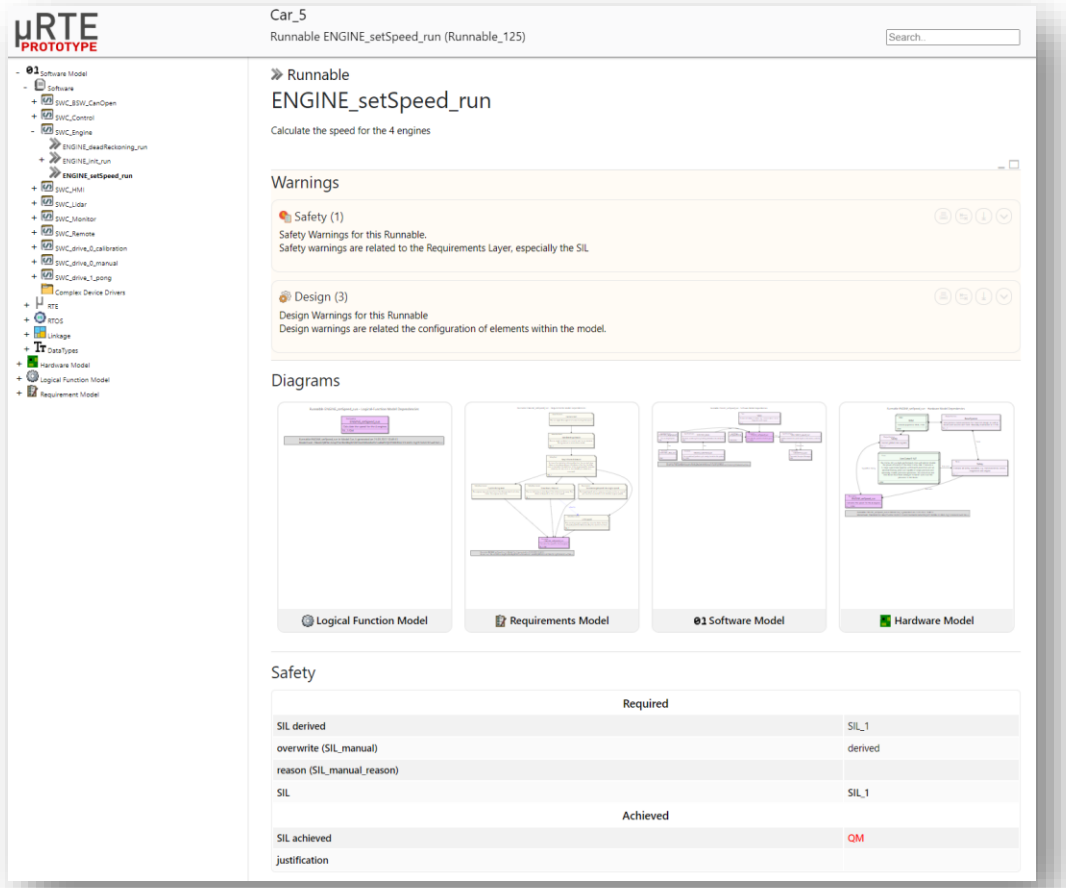
Derivation of requirements
Relationship (refinement/conflict) among requirements
Mapping to implementation units

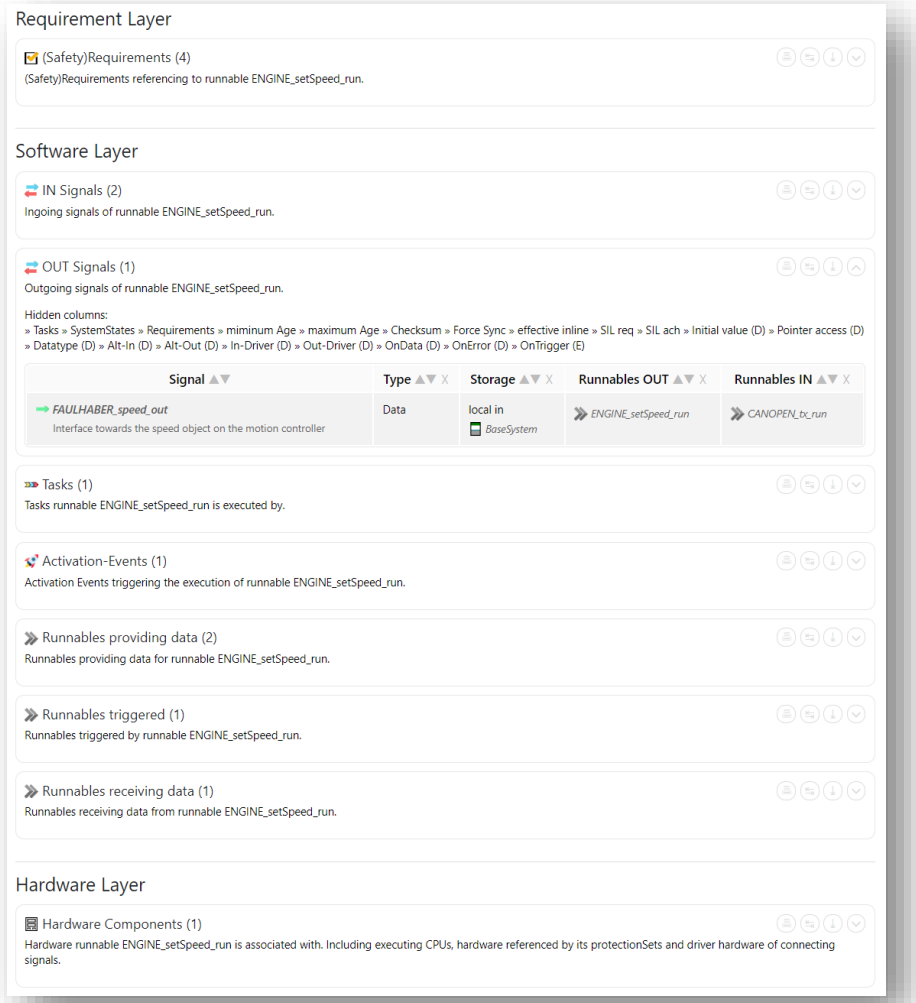
- µRTE System Model
  - Software Model
  - Hardware Model
  - Logical Function Model
  - Requirement Model
    - Overview
    - Package Top Level Requirements
    - Package Hazard and Risk Analysis
      - Hazardous Event Not responding to manual driving command
      - Hazardous Event Not detecting obstacle
      - Hazardous Event Wrong actuator action
      - Hazardous Event Wrong targetspeed / controlspeed calculation
      - Hazard Scenario Human crash
    - Package Safety Goals
      - Safety Goal Respond to user input
      - Safety Goal Stop in front of obstacle
      - Safety Goal Supervise engine
      - Safety Goal Plausibility of targetspeed values
    - Package Communication
      - Safety Requirement Verify transmission protocol
        - refined by Check structure and CRC of received XBee data package
        - refined by Check age of transmission protocol
      - Safety Requirement Check age of transmission protocol
      - Requirement Dispatch received protocol



Report

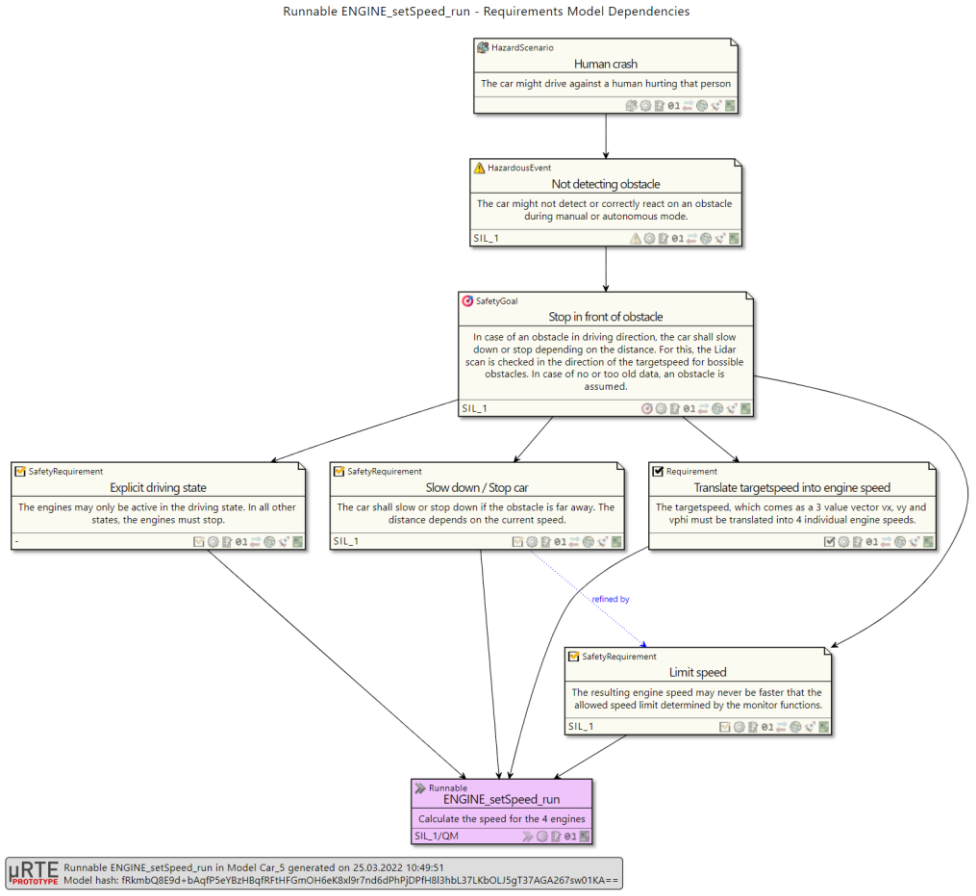
Generated as HTML
Each object in the model has a an own report page
Properties and dependencies are shown textual and graphical

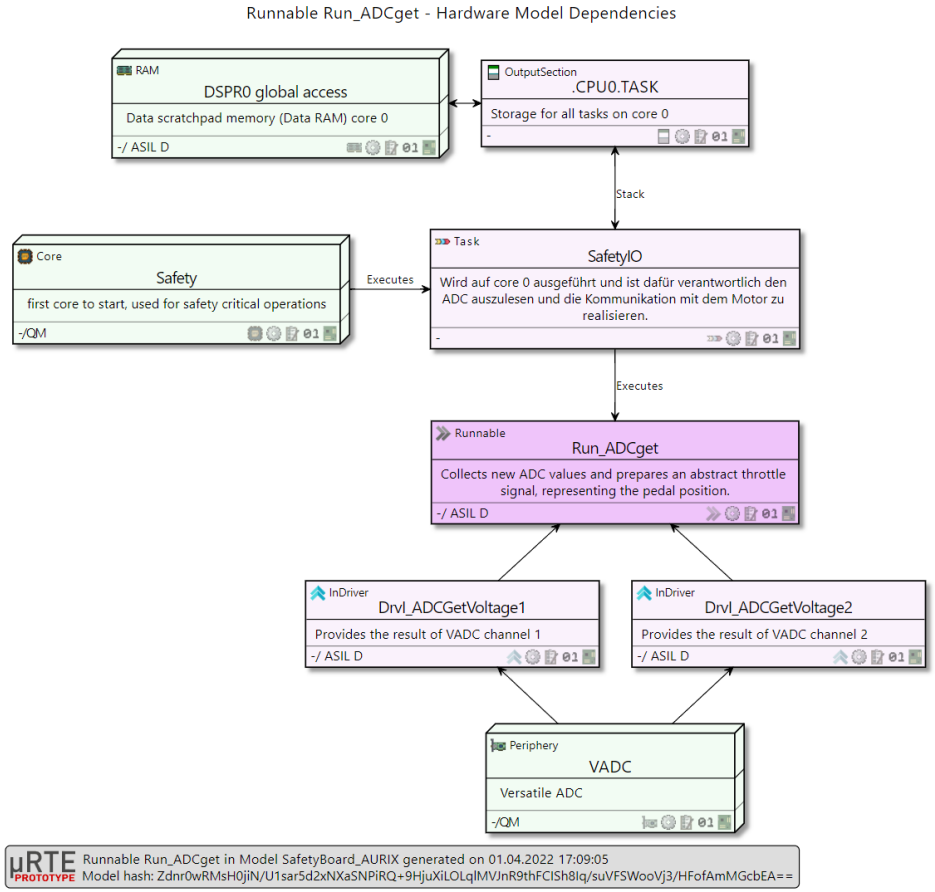




Report

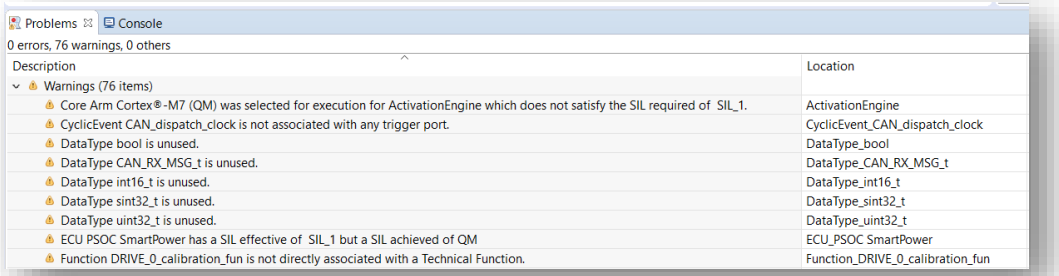
Generated as HTML
Each object in the tree has a an own report
Properties and dependencies are shown textual and graphical

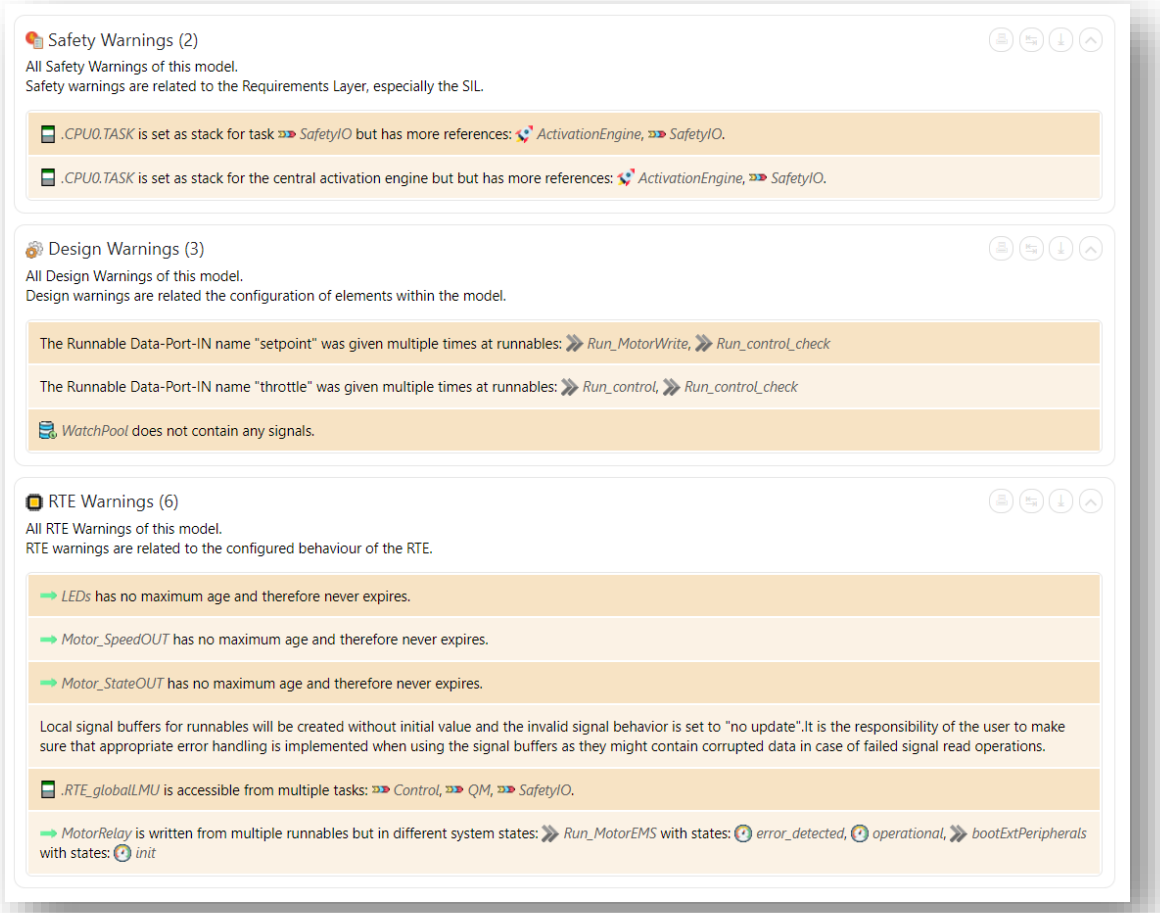




Report

Checkers for inconsistency, safety and design
Warnings are reported as globally and associated with affected elements





Code

Runnables and other functions (Drivers etc.):
Developer works in designated code blocks
Documentation and dependencies are generated as comment

```
/* ------------ Runnable "ENGINE_setSpeed_run" ------------
 * Calculate the speed for the 4 engines
 *
 *  User-ID:        Runnable_125
 *  SystemStates:   "normal"
 *  WCET:           0
 *  Stack:          0
 *  ROM:            0
 *
 * --- Triggers ---
 *      - TriggerPort "TI_ENGINE_setSpeed_run_50_0ms"
 *          Task: "Safety"
 *          System Events:
 *              - Cyclic Trigger "setSpeedClock" Cycle Time: 50, Offset 0
 *
 * --- Data Signals IN ---
 *      - DataPort "DI_CONTROL_limits" User-ID: SWDataPort_129
 *          Signals:
 *              - "CONTROL_limits" User-ID: SignalDataObject_14:
 *                  Description:        Structure containing driving limiting parameters like maxSpeed
 *                  Age:                Max: 300
 *                  Storage:            Signalpool "Safety"
 *                  Payload Datatype:   generated, see #CONTROL_limits_cfg.h
 *                  Runnables writing to this signal:
 *                      - SWC "SWC_Monitor"
 *                          - "Monitor_cyclicCheck_run"
 *
 *      - DataPort "DI_CONTROL_targetspeed" User-ID: SWDataPort_126
 *          Signals:
 *              - "CONTROL_targetspeed" User-ID: SignalDataObject_16:
 *                  Description:        The car targetspeed
 *                  Age:                Max: 300
 *                  Storage:            local signal
 *                  Payload Datatype:   generated, see #CONTROL_targetspeed_cfg.h
 *                  Runnables writing to this signal:
 *                      - SWC "SWC_Control"
 *                          - "CONTROL_drive_run"
 *
 * --- Data Signals OUT ---
 *      - DataPort "DO_FAULHABER_speed_out" User-ID: SWDataPort_128
 *          Signals:
 *              - "FAULHABER_speed_out" User-ID: SignalDataObject_20:
 *                  Description:        Interface towards the speed object on the motion controller
 *                  Storage:            local signal
 *                  Payload Datatype:   generated, see #FAULHABER_speed_out_cfg.h
 *                  Runnables reading from this signal:
 *                      - SWC "SWC_BSW_CanOpen"
 *                          - "CANOPEN_tx_run"
 *                  Trigger:
 *                      OnData:
 *                          - "TI_CANOPEN_tx_run_FAULHABER_speed_out_onData" triggering runnable "CANOPEN_tx_run" in Task "Safety"
 *
 * --- SAFETY ---
 *      SIL manual:     derived
 *      SIL effective:   SIL_1
 *      SIL achieved:   QM
 *
 * --- Requirements ---
 *          - "Translate targetspeed into engine speed"
 *              Description:
 *                  The targetspeed, which comes as a 3 value vector vx, vy and vphi must be translated into 4 individual engine speeds.
 *
 * --- SafetyRequirements ---
 *          - "Explicit driving state" SIL effective: derived
 *              Description:
 *                  The engines may only be active in the driving state. In all other states, the engines must stop.
 *              Other References of the SafetyRequirement:
 *                  - Runnable Monitor_cyclicCheck_run
 *          - "Limit speed" SIL effective:  SIL_1
 *              Description:
 *                  The resulting engine speed may never be faster that the allowed speed limit determined by the monitor functions.
 *          - "Slow down / Stop car" SIL effective:  SIL_1
 *              Description:
 *                  The car shall slow or stop down if the obstacle is far away. The distance depends on the current speed.
 *              Other References of the SafetyRequirement:
 *                  - Runnable Monitor_cyclicCheck_run
 *
 *
 * Start of user code ENGINE_setSpeed_run implementation notes
 *
 * End of user code
 */
void ENGINE_setSpeed_run(

        /* Trigger */
        const uRTE_Triggers_t triggerPort,

        /* Incoming Data-Signals */
        Signal_CONTROL_limits& sig_IN_CONTROL_limits,   /* Structure containing driving limiting parameters like maxSpeed */
        Signal_CONTROL_targetspeed& sig_IN_CONTROL_targetspeed, /* The car targetspeed */

        /* Outgoing Data-Signals */
        Signal_FAULHABER_speed_out* const p_sig_OUT_FAULHABER_speed_out /* Interface towards the speed object on the motion controller */
){

    //local IN signal value buffers
    Signal_CONTROL_limits::data_t CONTROL_limits_data;
    Signal_CONTROL_targetspeed::data_t CONTROL_targetspeed_data;

//Start of user code implementation ENGINE_setSpeed_run
```

Code

Internal code:
Focus on readability and simplicity
Generic and minimalistic low level interfaces for easy integration
Avoidance of inheritance with dedicated code generated for each element

```
uRTE_boolean_t Signal_ADC1::isValid(void) const {

    //return value buffer
    uRTE_boolean_t ret = false;

    //check if signal is in the valid state
    ret = uRTE_SignalStatus_valid==this->m_content.m_status;

    //check age only if previous steps succeeded
    if(uRTE_true==ret){

        //signal age buffer
        const uRTE_SignalTime_t signal_age = uRTE_getTimeStamp() - this->m_content.m_timestamp;

        //check if the signal is older than the maximal age
        if(SIGNAL_ADC1_AGE_MAX<signal_age){

            //signal is too old
            ret=uRTE_false;
        }

    }

    //check checksum only if previous steps succeeded
    if(uRTE_true==ret){
        ret = uRTE_checkChecksum(&(this->m_content), sizeof(Signal_ADC1::content_t), this->m_checksum);
    }

    return ret;
}
```

Signal internal code

```
static const PxProtectRegion_T Task_Control_Regions[] = {

    //RTE
    uRTE_TAE_CONTROL_MEMPROTSET

    //do not remove this line!
    {0,0,(PxProtectType_t)0}
};

void CTask_Control::Task_Func(PxTask_t myID, PxMbx_t myMailbox, PxEvents_t myActivationEvents)
{
    //Run activation engine
    uRTE_TAE_Control::Run();

}
```

Task integration

µRTE workflow

Integration
µRTE needs to be integrated onto a specific target and RTOS once

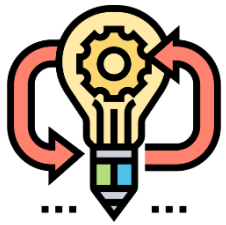
Requirements
The behavior of the system including safety requirements is defined

Architecture
Definition of hardware, data-flows and overall software-structure

Generation
Report and Code-Frame
Existing user-code is preserved

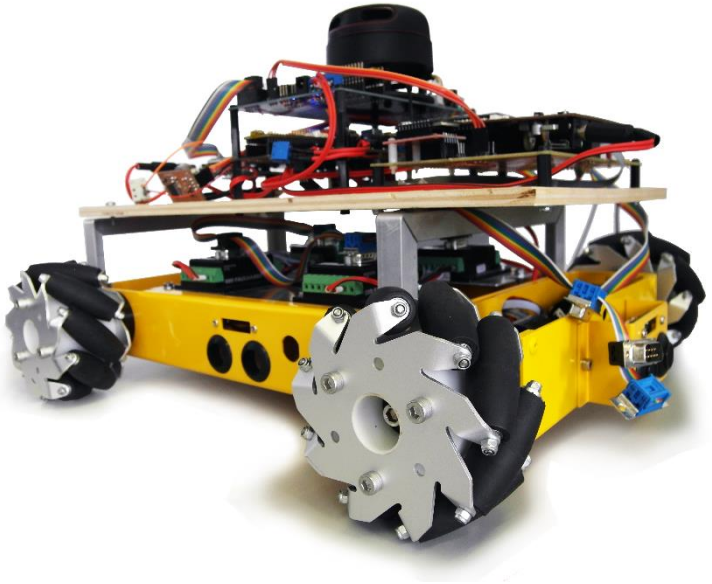
Development
Implementation of functionalities within the generated code-frame based on the report

Test and Qualification
Unit, integration and system tests based on the report supported by the uniform structure of the generated code



Iterative work and late changes possible even on architectural level

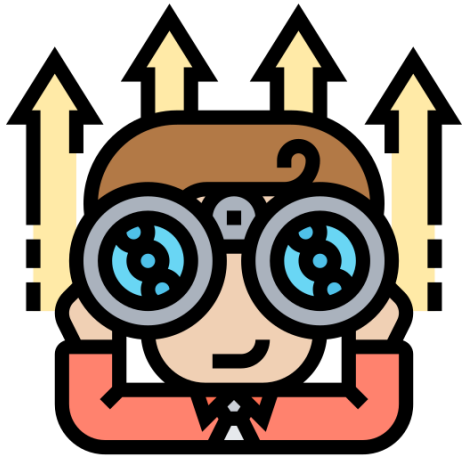
Experience



µRTE Demonstrator

- Fast familiarization
- Code focus moves to architectural focus
- Significantly improved system understanding
- Architectural refactoring support
- Cross platform reusability
- Good code analyzability / debugability

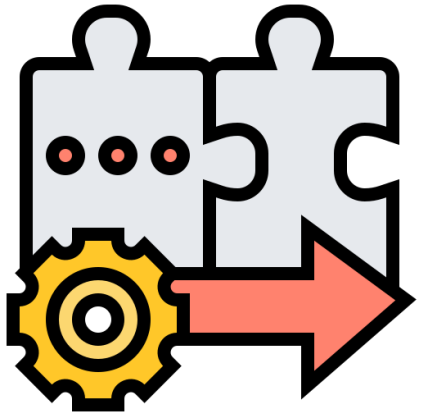
Possible extensions



- Test-Framework generation (WIP)
- OS-less implementation
- Extension towards interrupts, centralized error handling and more
- Certifiable implementation
- Readback of generated artifacts and comparison against model
- Linkage to other tools, CI/CD etc.

Integration

Interfaces



- One additional system task with central tick
- Tasks are not generated
- Global timestamp source
- Interfaces for inter-task messaging and notification