Zerberus System
A tool chain for the development of augmented reality applications

Personal Background

- Ph.D. at the University of Munich
- Chair VI: Embedded Systems and Robotics
- Interests: safety critical applications, real-time systems, development models

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Introduction

Example application: Medical assistance

Task: Assistance during an minimal-invasive operation

Sensors:

- Ultrasound
- Video
- magnetic resonance imaging
- Computed tomography scans

Requirements:

- Safety
- Real-time

Further Applications:

Telemedicine -> Reliability

Example application: Robotics

Task:

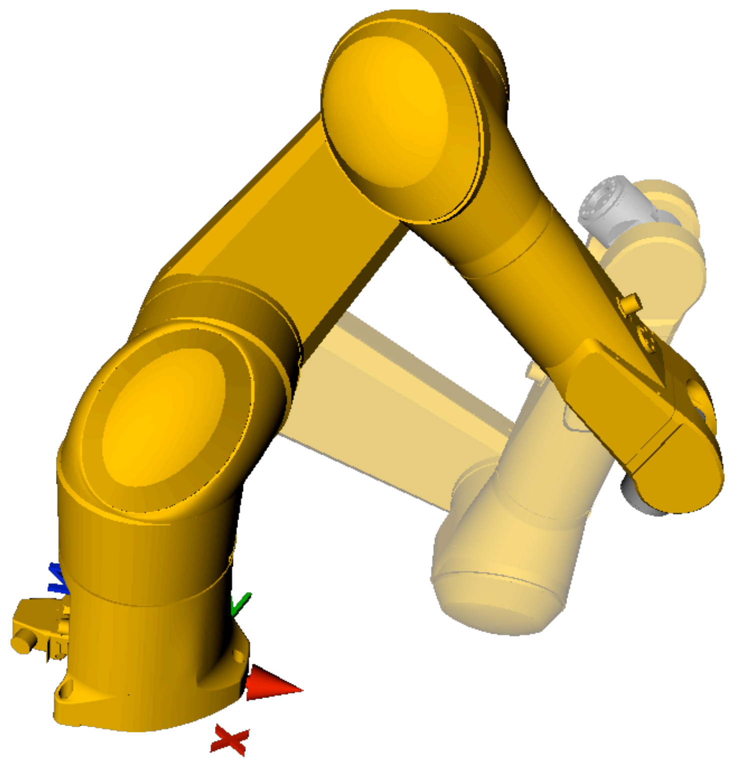
- Remote robot control
- Simulation of robot movements

Sensors:

- Video
- Servos

Requirements:

- Safety
- Reliability



Example Application: Visual Annotation

Task:

- Assistance in maintenance

Sensors:

- Video
- User Input (buttons, voice)

Requirements:

- Real-time

Summary of Requirements:

- Safety
- Reliability
- Real-time
- Different sensors
- Distributed computing

- Time consuming computations
  ⇒ Portability to new more powerful hardware

Requests on development models

- Simplicity
- Cost-efficiency
- Development process acceleration
- Tool support
- Automatic code generation
- Usability by application domain expert
- Inherent safety

Zerberus System

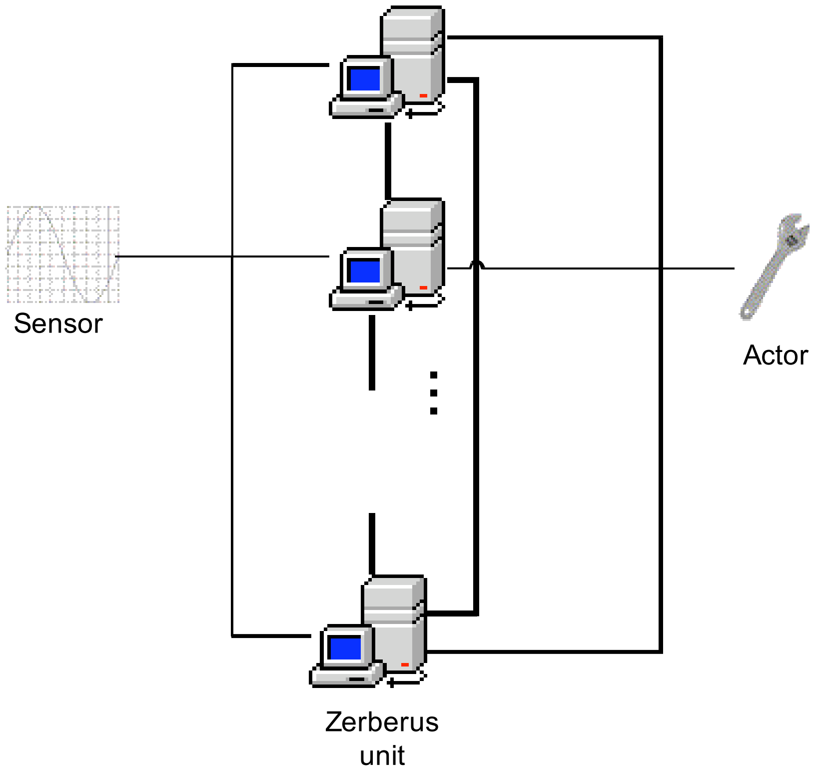
Background

- Current development process for safety critical applications:
  - Development is based on internal experiences of the company
  - Many domain experts are involved (real-time systems, fault-tolerance, application domain)
  - certification authority can only check if standards are met
  - long-lasting, error prone development process
  - Time and cost-intensive

Zerberus Approach

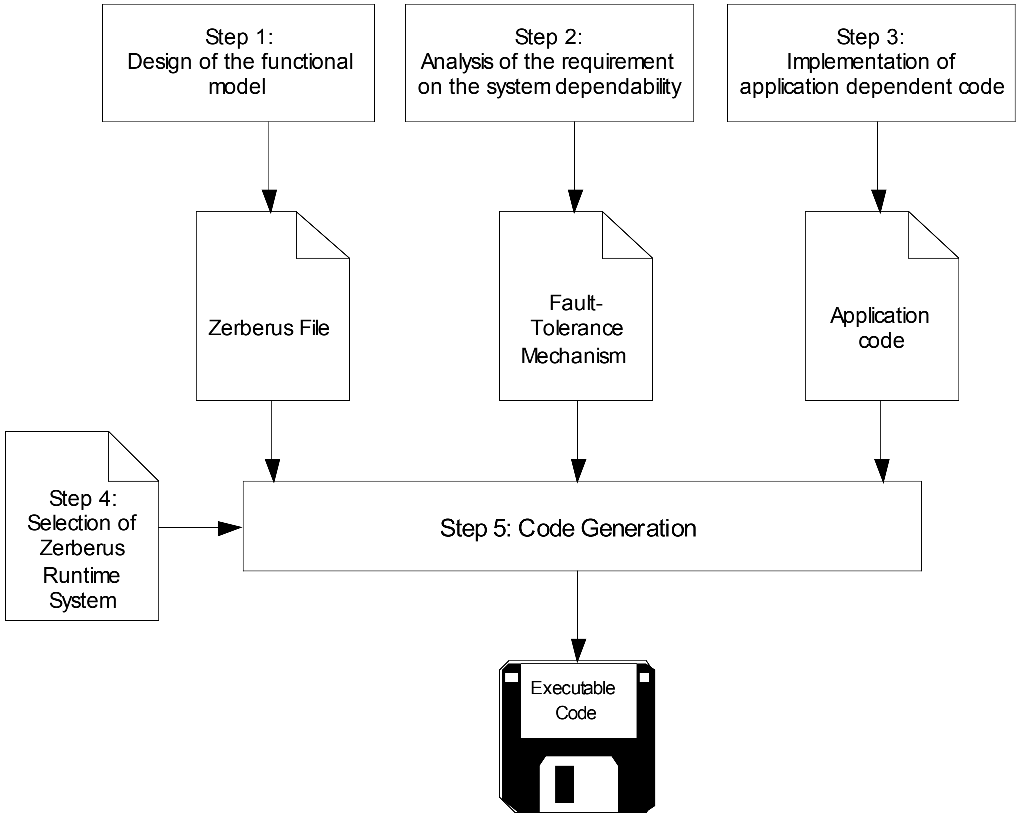
- Suggestion of a development model
- Provision of a tool chain
- Support of automatic code generation
- Based on commercial-of-the-shelf hardware
- Platform independent specification of the functional model
- Timing restrictions can be specified directly in the functional model
- Automatic realization of fault-tolerance mechanisms
- Only application-dependent code has to be implemented by the developer

Fault-tolerance mechanisms



- Active structural redundancy
- Diversity in hardware and software is supported
- Developer can choose the appropriate level of fault-tolerance

Development process



Requirements on the specification language

- Division of the application into the functional parts
- Determinism
- Specification of temporal constraints

For fault-tolerance mechanisms:

- Replica determinism
- State synchronization

Zerberus language introduction

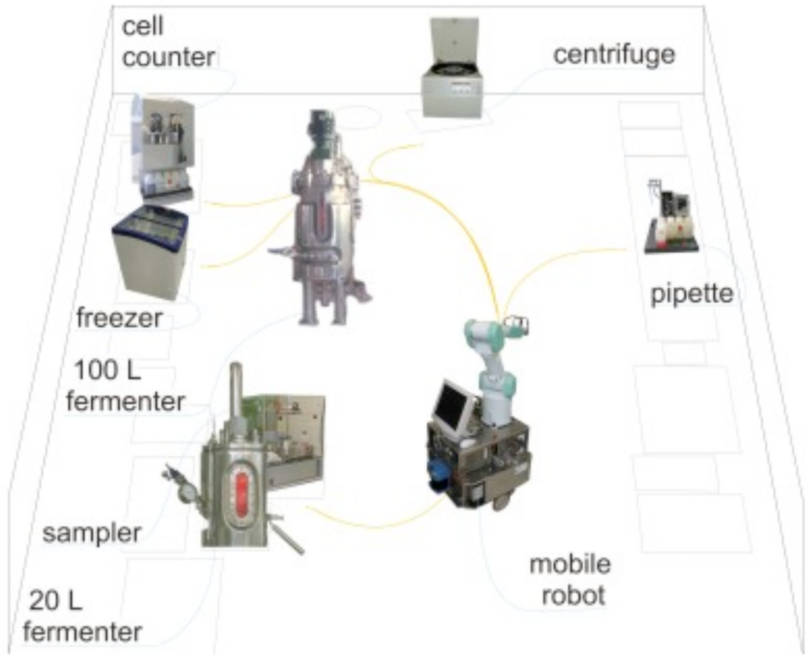
Attributes:

- Time-triggered
- Platform independent
- Intuitive and simple (only 7 object types)
- Extendable
- Few restrictions on IO

Introductory example

Task:

- Robot should move in the laboratory without collisions
- Robot should pick up objects and move them to targets
- Jobs are send to the robot via wireless LAN
- Via radio the robot can determine its position



Separation of inner state: Ports

- Ports are distinct places in memory
- Specified size
- Representation of values is unique on all platforms
- Read- and write accesses are performed time-triggered -> determinism
- Voting algorithms are based on the port values
- Integration of units is based on port values

Ports in the application:

- Object coordinates
- Target coordinates
- Joint settings
- Motor settings
- Camera data
- Job Queue
- Robot path plan
- Path plan for robot arm

Robot coordinates

Job Queue

Camera data

Robot path plan

Robot arm path plan

Motor settings

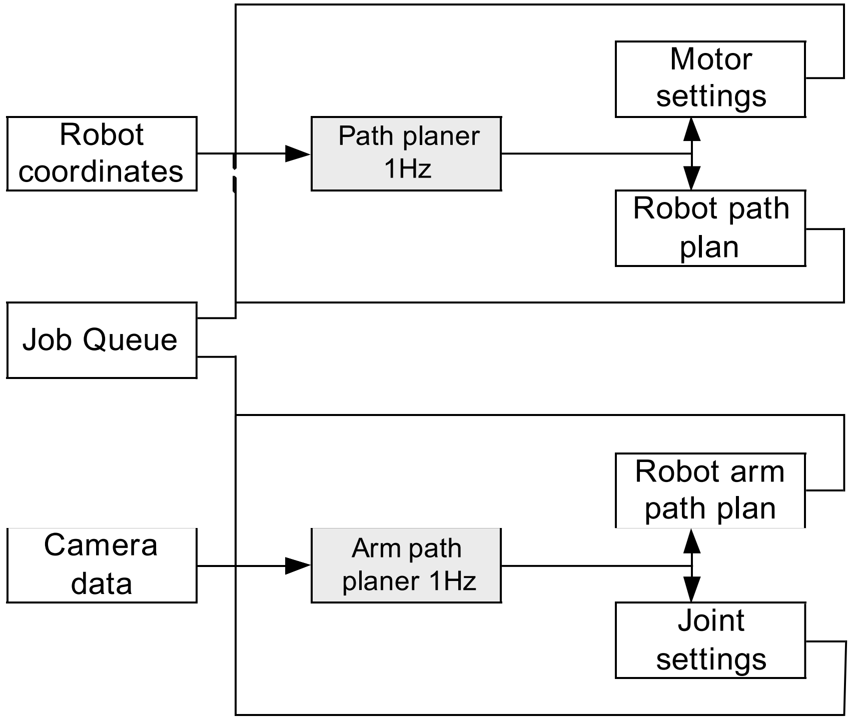
Joint settings

Functional Elements: Tasks

- Periodically called functions
- No inner synchronization points
- All communication between tasks is performed via ports
- Tasks start logically at the begin of each period and finish at the end of the assigned period
- The physical execution on the CPU is transparent to the user

Application Tasks:

- Path planer
- Robot arm path planer



Problem: Bumpy curves

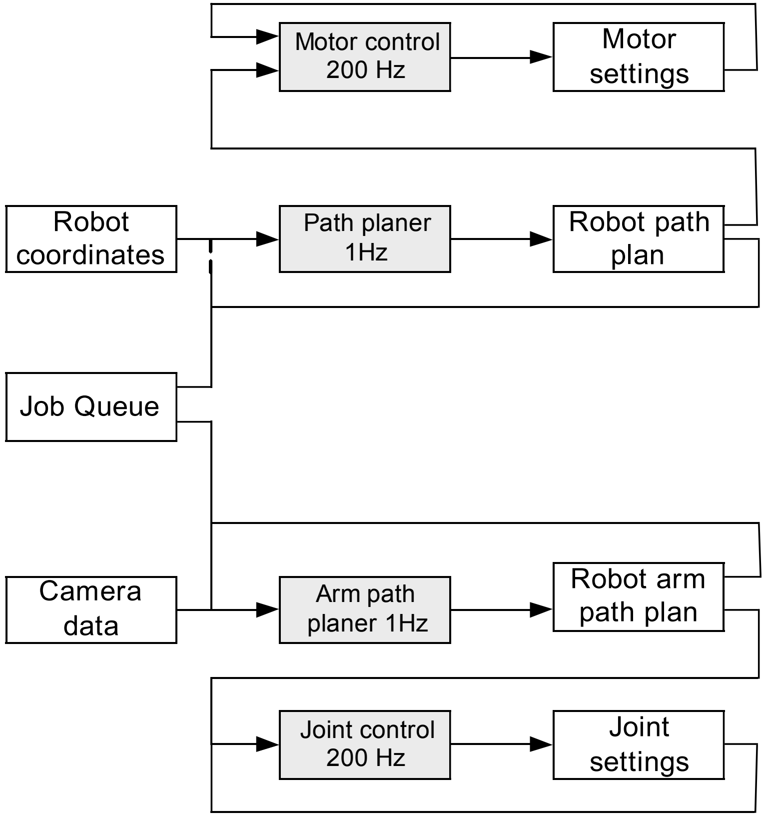
⇒ Long execution times

⇒ Bumpy curves

⇒ Introduction of steering tasks:

- Motor control task

- Joint control task

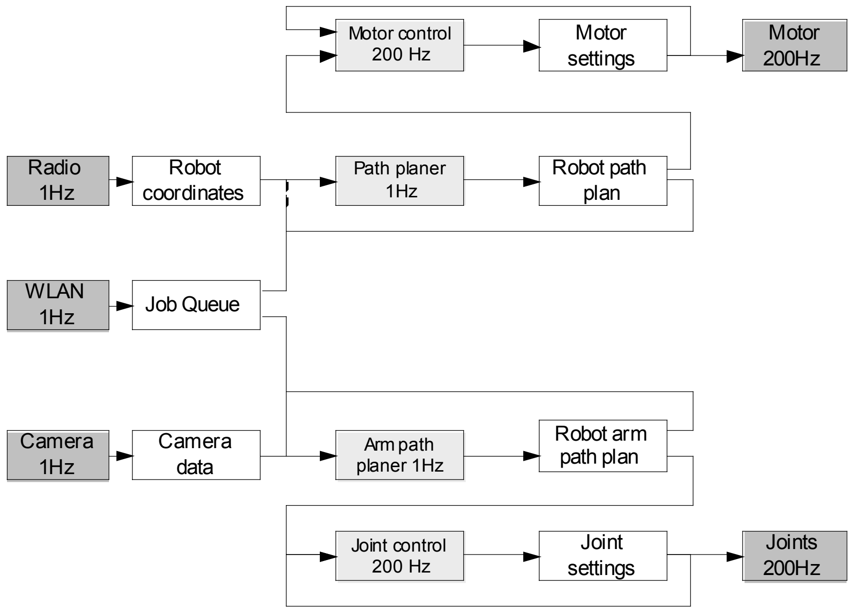


Realization of IO: Sensors and Actors

- Simple IO functions
- Execution occurs time-triggered
- IO functions are executed within the run-time systems context
- Synchrony assumption: execution is performed instantaneous

Application IO

- Sensors:
  - Camera
  - WLan
  - Radio
- Actors:
  - Motor
  - Joints



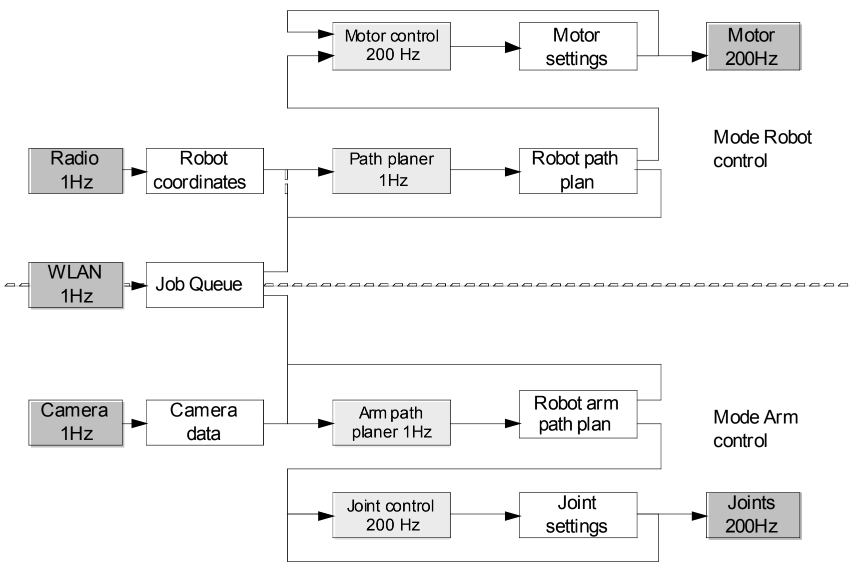
Supporting different application modes: Mode

General:

- Set of tasks, sensors and actors with specified execution frequencies
- Specified mode cycle duration

Application Modes:

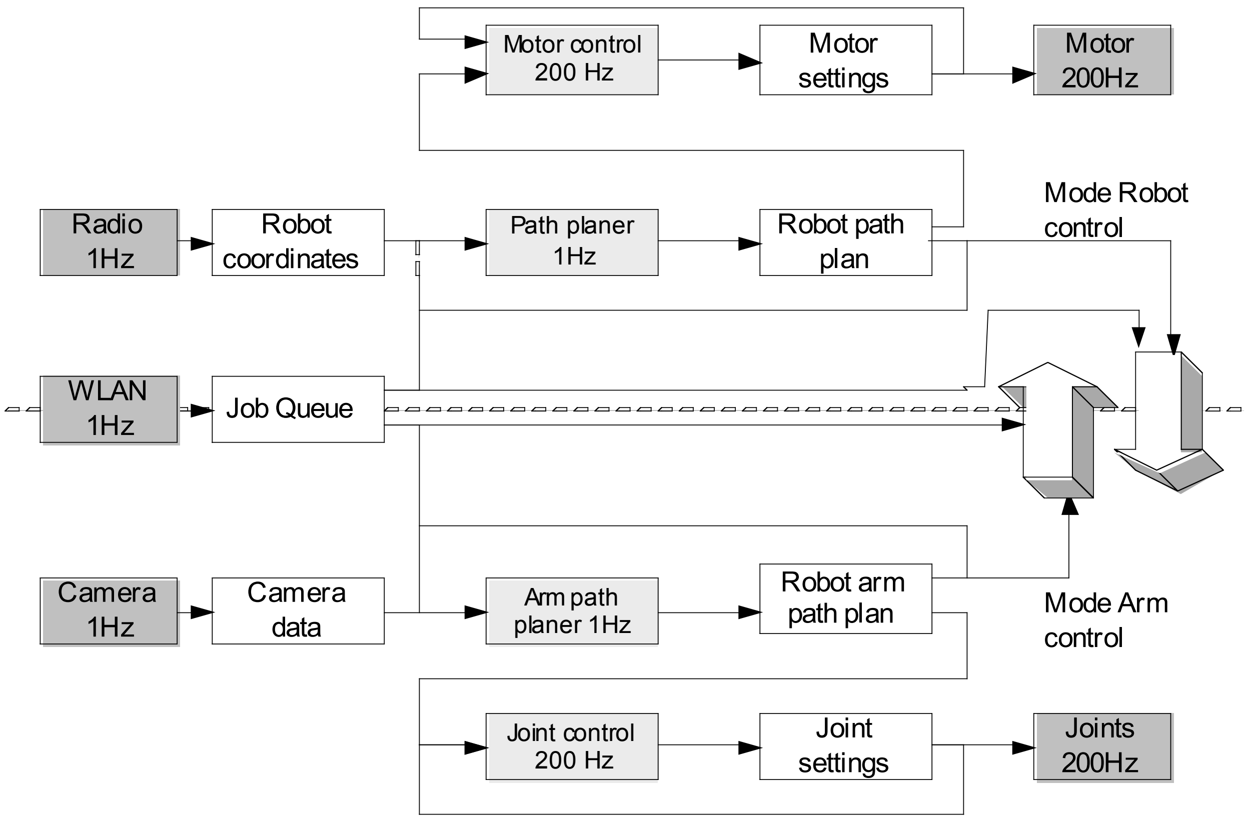
- Robot movement towards objects or goals
- Robot arm movement



Switching the context: modechanges and guards

- Binary functions based on port values
- Executed in run-time system's context (synchrony assumption)
- Modechanges: way to change modes (only at the end of one mode cycle possible)
- Guards: more precise possibility to control the application

The whole application:



Execution Model:

Steps performed by the system in each round:

1. Termination of tasks
2. Voting and synchronization
3. Actor execution
4. Modechange evaluation
5. Sensor execution
6. Task start
7. Advance time

Logical execution

mode mode1

{

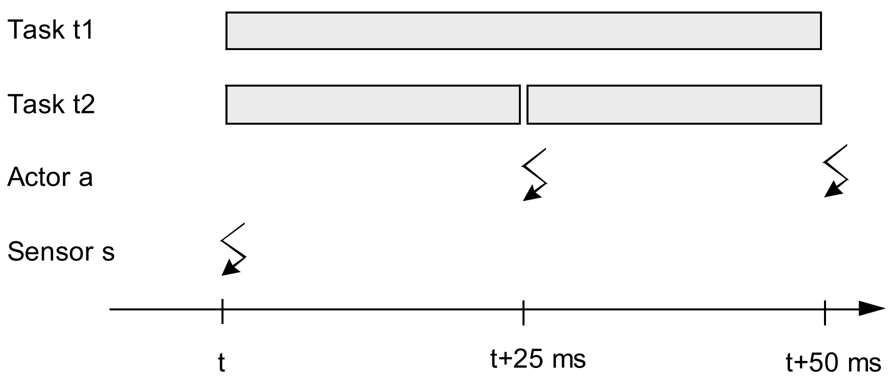
task= t1 1, t2 2;

actor=a 2;

sensor=s 1;

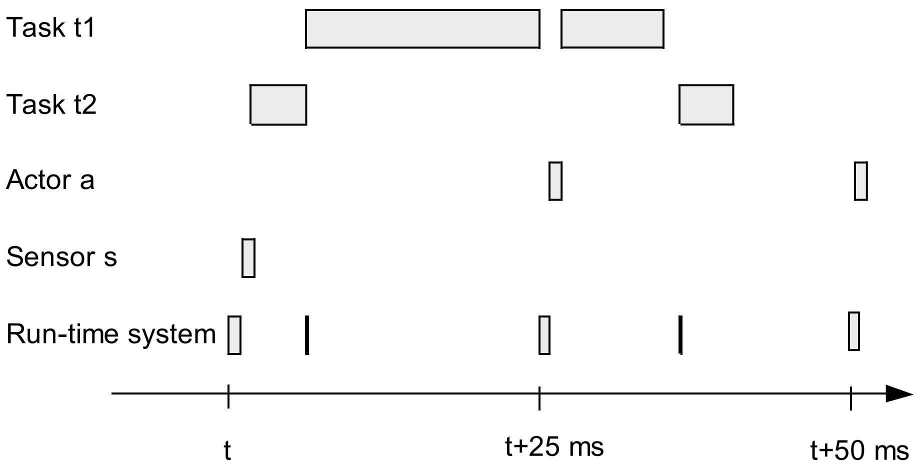
duration= 500000000 ns;

}



Simple mode declaration

Actual execution



Further steps in the development process

Step 2: Implementation of application dependant functions

Functions that have to be implemented:

- task functions
- sensor functions
- actor functions
- modechange functions
- guard functions

Step 3: Selection of fault-tolerance mechanisms

Currently supported:

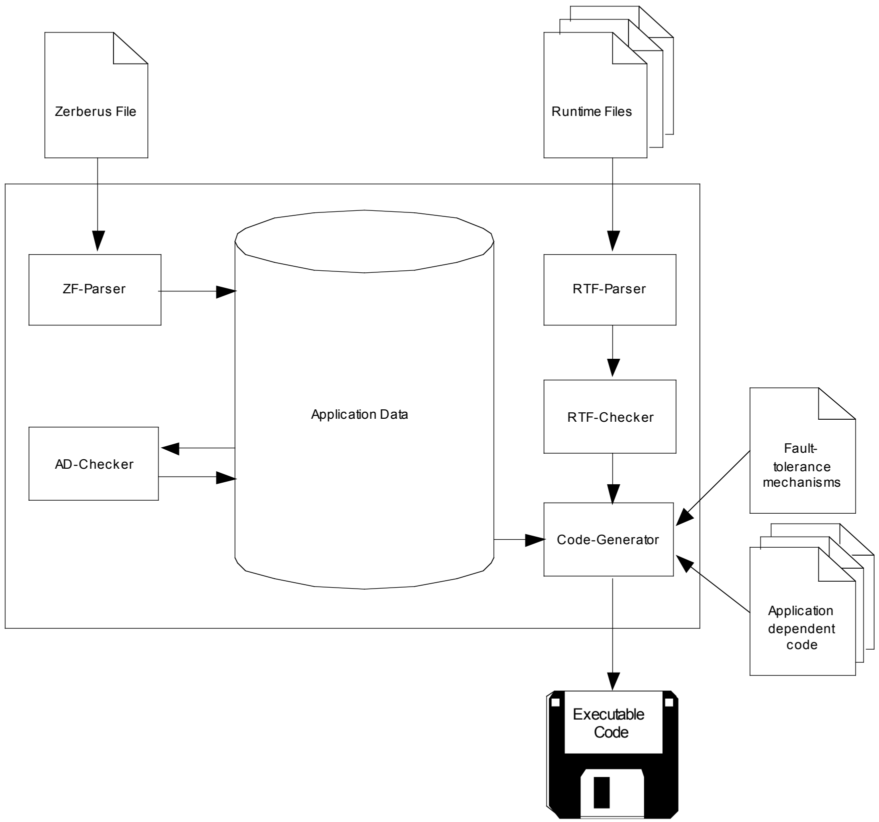
- Active structural redundancy
- Hardware diversity
- Software diversity (N-Version programming)

- others will be supported

Step 4: Selection of platform

- Zerberus run-time systems are provided for different platforms
- Run-time systems realize the execution of Zerberus applications, the synchronization, integration and voting
- Extensibility: User can implement own run-time systems
- Reusability: Zerberus tags to support application independent implementation of run-time systems

Step 5: Code Generation



Augmented Reality: Using the Zerberus System

Requirements:

- Safety ok
- Reliability ok
- Real-time ok
- Different sensors ok
- Distributed computing ok
- Portability to new more powerful hardware ok

But:

- Current need for redundancy
- Destructive voting

Demands:

More flexible layout of the applications:

- limiting the needs for redundancy:
  - single unit applications
  - single application processes

- using results of different units in a more constructive way
  - merge of redundant results (e.g.: in case of different sensors)

More flexibility:

- Abdication of need for redundancy
  - Introduction of a possibility to spread the different tasks on the units
  - relocation of tasks in case of a unit failure
  - Tool supported task assignment
- Solution for augmented reality:
  - Use of redundancy only if safety standards have to be met

Constructive voting

- Separation of functional design and fault-tolerance
  - Events: Deterministic points in time to execute fault tolerance mechanisms (voting, plausibility tests)
  - Exception: Occurrence of faults
  - Handling: Fault reaction (separation of faulty unit, process rollback, constructive methods, application dependant reactions)
- Solution for augmented reality:
  - introduction of an interface for application dependant mechanisms

Literature:

- Christian Buckl: Implementierung eines Entwicklungssystems für fehlersichere und zuverlässige Kontrollsysteme, February 2004.

- Christian Buckl: Zerberus Language Specification Version 1.0., Technical Report TUM-I0501, TU Munich, January 2005.

- Dhiraj K. Pradhan: Fault-Tolerant Computer System Design. Prentice Hall, 1996.

Summary:

- Requirements regarding typical augmented reality applications were gathered
- The Zerberus System can fulfill these requirements
- Solutions for remaining problems were suggested

Let's discuss