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THE CONCEPT OF FUNCTIONS AND INFORMATION CONVERSION IN SOFTWARE - DESIGN METHOD ADAPTATION IN AN INDUSTRIAL CONTEXT

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1. Introduction

Solving engineering design problems aims at creating technical systems to perform specified tasks. Re-use of existing design solutions can increase engineering design process efficiency and can contribute to technological maturity of these design solutions. Re-use requires identification of solutions and an evaluation of their applicability and adaptability with respect to given tasks. In this context, the concept of functions is essential to methodical engineering design procedure, since functions define intended purpose in a solution-neutral way, and the approach provides increased understanding of design solutions [Pahl et al 2005].
In innovative technical systems, electronic solutions in combination with software increasingly supplement mechanical solutions. Therefore, software component re-use offers considerable potential for optimisation of engineering design processes, and of products. Prerequisite for efficient re-use is availability of electronic product data. In the case of software components, this concerns for example specifications of intended working environments, and stability and performance aspects. Especially, comprehensive description of software functions is required, since these serve as principal criteria for task-oriented selection. Neither methodical nor IT support is currently sufficient for re-use or distribution by means of electronic marketplaces of software components.
To apply the concept of functions to software components, adaptation of this method is required to consider the nature of software as an abstract logical system. To this end, this paper applies an approach to design method development focusing information conversion to adapt the concept of functions to the specifics of software components. A software component repository prototypically implements the resulting method for functional specification. The industrial context for method adaptation and prototypical implementation was the field of automation technology, but the results are applicable in other domains as well.

2. Methodology

2.1 Analysis of method development from a process perspective

A *method* is a set of instructions, whose execution under given conditions sufficiently ensures the achievement of an intended objective [Mueller 1990]. A *process* is a set of activities that uses resources to transform inputs into outputs [ISO 9000:2000]. According to this, a method is a description of a set of activities, i.e. an abstraction of a process. Its purpose is to provide support for operators in processes. At the same time, a method is an (intangible) product, which is the result of a (method development) process. In this context, the term *meta-method* refers to methodical support of method development processes, i.e. a meta-method is an abstraction of a method development process.

This analysis results in the distinction of three different levels of abstraction in the context of method development. Their distinction facilitates the identification of conditions that are constitutive for method development, adaptation, implementation, and application (Figure 1).

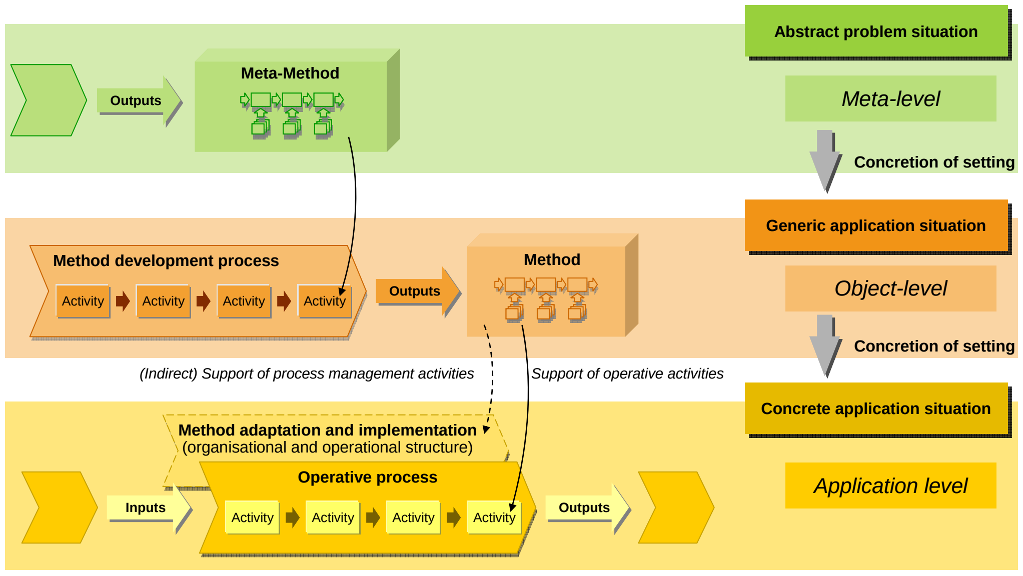

Abstract problem situation
Outputs
Meta-Method
Meta-level
Concretion of setting
Generic application situation
Method development process
Activity
Activity
Activity
Activity
Outputs
Method
Object-level
Concretion of setting
(Indirect) Support of process management activities
Support of operative activities
Concrete application situation
Method adaptation and implementation
(organisational and operational structure)
Operative process
Inputs
Activity
Activity
Activity
Activity
Outputs
Application level

Figure 1. General context of method development

At application level, operators face concrete tasks, e.g. the development of one concrete product. Such tasks constitute concrete application situations. Methods are supposed to be invariant for a certain class of tasks [Mueller 1990]. For this reason, method development usually considers generic application situations, e.g. product development tasks per se. Such generic application situations instantiate abstract problem situations.
Methodical support at application level is required to work twofold. On the one hand, methodical support aims at individuals performing operative problem solving activities within operative processes. On the other, it is required to support process management activities. Process management often employs decision gates, i.e. generic descriptions of information to which the results of operative activities are compared for the purpose of decision-making [ISO/TS 16949].

2.2 Framework for process-oriented method development based on information conversion

In this context, a process-oriented approach to method development is proposed, which focuses on concrete information at application level, on information properties at object-level, and on abstract information conversion aspects at meta-level. These information conversion aspects are organisational, technological and psychological aspects of information conversion. They are referred to as fluency, form and content, since they are interrelated mainly to communicating, representing and processing of information, respectively.
The approach applied in this paper structures the process of method development, adaptation and implementation according to the generic information conversing activities analysis, acquisition, consolidation, and definition. In the stage of method development, the principal focus of these activities is on information conversion. In the stage of method adaptation and implementation, it is on resources, shifting from qualitative aspects (resource capabilities) to quantitative aspects (resource capacity) (Figure 2).
The resulting meta-methodical framework[3] proposes an iterative procedure for method development, consisting of a sequence of principal activities applied to information conversion, with the focus

[3] This framework and its application are discussed in more detail in [Weigt 2005].

shifting from fluency to form to content. As a result, the procedure considers organisational requirements and those regarding the handling of information before the actual information processing. The procedure starts with an analysis of the process boundaries and interfaces, and a rough outline of input information properties. This provides foundation for specification of further input acquisition and input consolidation steps, which allows outlining transformation activities (definition) and output consolidation steps. The result is a conceptual method schema, i.e. a schematic outline of operations that describe how to transform input into output. Iterative refinement of this schema considering information properties will then result in an increasingly detailed network of information conversing operations that are logically interrelated by information flows. This procedure therefore helps to establish a stepwise transition from "what" a method is supposed to achieve towards "how" to achieve this.

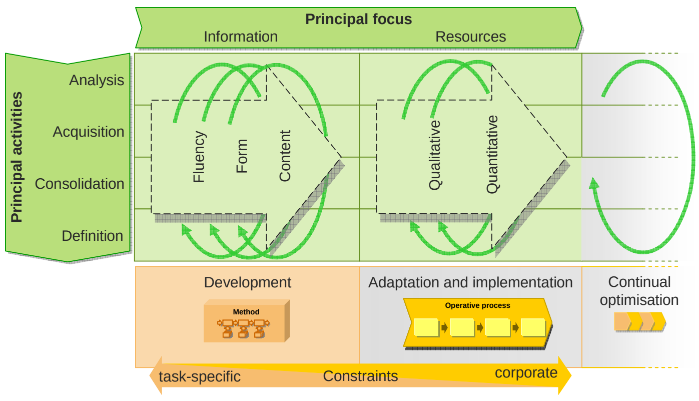


Figure 2. Meta-methodical framework

Focusing on information properties leads to an increased transparency of working principles of methods. This facilitates assessment of applicability of existing methods and their adaptation. It also improves method usability and acceptance, and effectiveness and efficiency of their practical application. The proposed meta-methodical framework can therefore serve as an appropriate foundation for adapting the concept on functions to software components.

3. Functional specification of software components

3.1 Problem analysis

Software is an algorithm formulated by measures of programming. It is therefore a specific type of method, whose supportive properties result from interaction with hardware and generally other software within a working environment. The automation technology applications focused in this paper are usable in variable working environments (personal computers or programmable logic controllers), as long as these meet specific standards. The approach does not consider embedded applications.

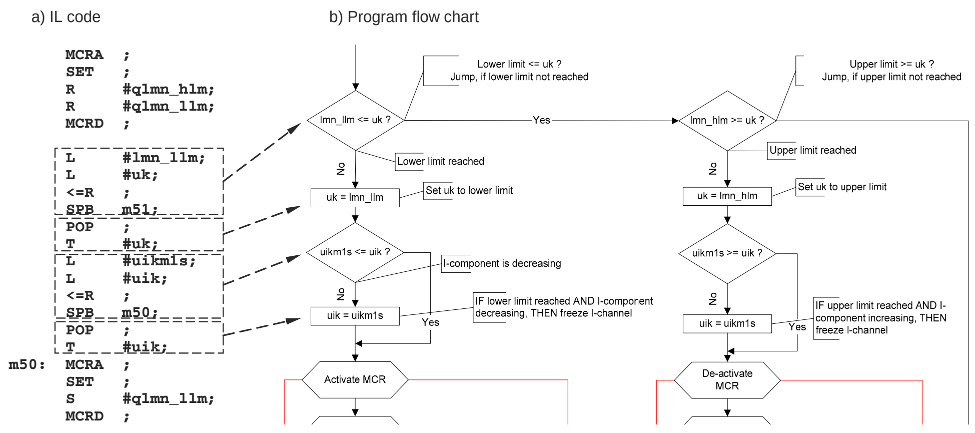
Software is not a physical product, but an abstract logical system. It implements logical statements of the form {P}S{Q}: If a precondition P is true, by execution of the program S the postcondition Q becomes true. Physical effects and laws are only relevant for software components as environmental conditions. Analysis is not the mathematical foundation of software development, but instead combinatorics, mathematical logic and algebra.

A function is defined as the desired input-output relationship of a definite and limited system, whose purpose is to perform a task [Pahl et al 2005]. Since software is not a physical system, physical effects and corresponding mathematical interrelations do not provide appropriate foundation for its functional specification. In a working principle-oriented perspective, inputs and outputs of software applications are data processed by means of an algorithm. A functional perspective onto technical systems requires the interpretation of this data in the context of the given task, providing meaning for the data. Therefore, against the background of functional specification, software can be considered an

information conversing system, and it is advisable to specify function, inputs, and outputs in the context of the task. While quantitative limitations to information conversion in software exist due to availability of computing time and memory, qualitative limitations do not exist per se.
Overall functions of software applications in automation technology result from the interconnection of so-called function blocks managed in libraries. These function blocks provide basic building blocks for control technologies [IEC 61131-3]. The resulting software is configurable, i.e. setting of certain parameters influences the functional behaviour of the building blocks and the entire software. Configurability specifically includes activation and de-activation of specific sub-functions.
The concept of working principles is well established in engineering design methodology. Principle properties of physical systems result from physical principles in combination with form design features [Pahl et al 2005]. Principle properties of software result from types of algorithms and types of data structures processed. Their combination provides a conceptual equivalent to the working principle of physical systems. Specification of function blocks according to [IEC 61131-3] is independent from tasks. Inputs and outputs state parameter names instead of what these inputs and outputs represent in the context of tasks. For this reason, these function blocks are more similar to the concept of working principles than to the concept of functions in engineering design methodology.

3.2 Method for the functional specification of software components

Consideration of *fluency* aspects of information conversion is not required in the context of this paper. It concerns a sub-process with specific process interfaces, which do not impose relevant constraints for its integration into the greater organisational and operational structure of the company.
At the cooperating company, the principal input information for functional specification is source code, including varying degree of textual commentary. Instruction list (IL) [IEC 61131-3] is the programming language used. IL is a procedural language similar to Assembler. Readability of IL code for human users is limited, especially when optimised for time-critical applications. This imposes a *form-related corporate constraint* to method development. Insufficient *transparency* is a form-related input information property that is important in the context of this paper. Increasing transparency requires input information consolidation with respect to form. Constructing program flow charts can achieve this. This graphical-textual representation increases readability and understanding of structure and purpose of the source code (Figure 3).


a) IL code

```
      MCRA   ;
      SET    ;
      R      #qlmn_hlm;
      R      #qlmn_llm;
      MCRD   ;
      L      #lmn_llm;
      L      #uk;
      <=R    ;
      SPB    m51;
      POP    ;
      T      #uk;
      L      #uikm1s;
      L      #uik;
      <=R    ;
      SPB    m50;
      POP    ;
      T      #uik;
m50:  MCRA   ;
      SET    ;
      S      #qlmn_llm;
      MCRD   ;
```

b) Program flow chart

Figure 3. Excerpt from IL code and corresponding program flow chart

The following *content-related task-specific constraints* are essential for the adaptation of the concept of functions to software components:

- Software is not a physical system.
- No qualitative limitations exist to information conversion in software.
- The task of functional analysis and specification is typically of high complexity.
- The functional behaviour of software is highly configurable.

Since Software is *not a physical system*, neither physical effects nor form design features are directly relevant for the functional behaviour of software components. Generic properties of inputs and outputs, which are influenced by means of the information conversion within the software, cannot be meaningfully provided independently from the context of the task. Therefore, instead of the context-independent concepts of physical effect-oriented special functions [Roth 2000] or input/output property-oriented generally valid functions [Pahl et al 2005], task-specific functions [Pahl et al 2005] can serve as a foundation for the functional specification of software components.
Task specific functions derive directly from the task. Their problem-oriented formulation uses technical common speech. This provides the benefit of not being limited to a specific set of technical verbs and/or physical terms. Technical common speech can therefore appropriately specify information conversion in software, which is subject to *no qualitative limitations*.
The concept of functions in engineering design methodology proposes hierarchical structuring as a means of making manageable complexity. To manage the *high complexity* of analysis and specification tasks, hierarchical structuring is an appropriate means in the case of software components as well. However, resource-oriented optimisation measures may lead to discrepancies between concrete code structure and abstract function structure.
Software components typically not only fulfil a set function. Their function can be highly *configurable*, and the software can advise about its functional behaviour. This makes advisable to distinguish between configuration-related control flow and processing-related data flow when defining the relations between the elements of a software function structure.
In the context of time-related synchronisation of program execution in distributed working environments, [IEC 61499-1] distinguishes between data flow and event flow. This standard provides a graphical notation that depicts function blocks with a separate execution control "head" and corresponding event inputs and outputs. Even though this event flow does not relate to functional configurability, this type of graphical representation can be suitably adapted to distinguish between configuration-related control flow and processing-related data flow in a software function structure (Figure 4).

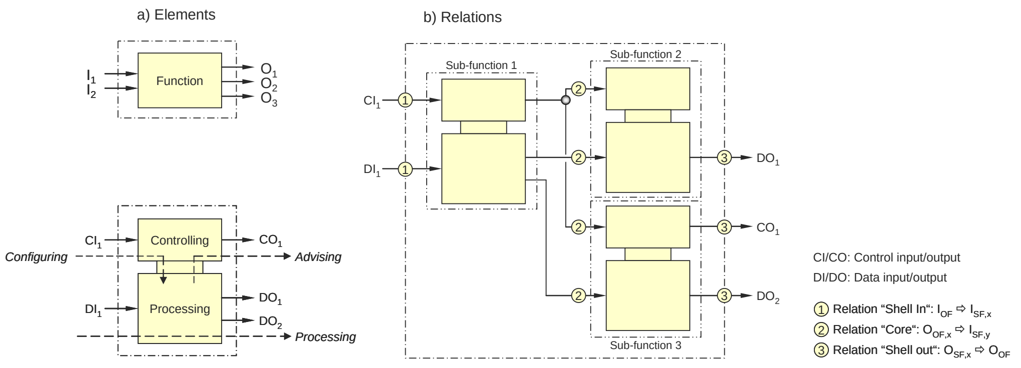
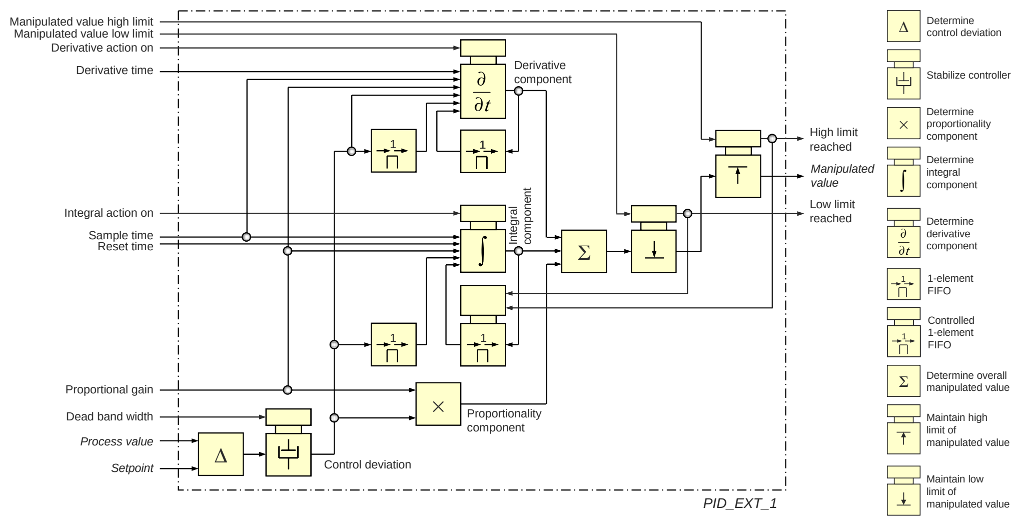


Figure 4. Elements and relations of software function structures

Sub-functions are *elements* of a software function structure. Their inputs and outputs are data inputs (DI), data outputs (DO), control inputs (CI) and control outputs (CO). DI and DO constitute the data flow. It carries data that is algorithmically processed, e.g. process parameters. Inputs and outputs that are essential for functional specification are usually part of the data flow. Their identification enables functional specification based on their processing (e.g. "suppress low control deviations") in addition to task-oriented functional specification (e.g. "stabilize controller"). The control flow supports structured specification of functional configurability. CI directly influence the functional behaviour of the software, while CO advise about it. *Relations* of the software function structure interconnect the inputs and outputs of overall function (OF) and sub-functions (SF), and of sub-functions among each other. Shell relations link sub-functions to the overall function. Core relations interconnect outputs and inputs of sub-functions.

The application context provides direction to determine the adequate *degree of resolution* of software function structures. In the case of development of new software applications, adequate degree of resolution depends on novelty of the task and on existence of solutions available for re-use. In the case of functional analysis and specification of existing solutions, the adequate degree of resolution depends on the degree of code optimisation: Resource-oriented boundary conditions motivate optimisation of time-critical applications, not the task per se. For this reason, with increasing degree of resolution, discrepancies arise between (resource-oriented) source code and (task-oriented) function structure. Beyond a certain degree of resolution, these discrepancies prevent re-use or adaptation for similar tasks with justified effort. Determination of this degree of resolution requires individual evaluation. As an example for a suggested degree of resolution, a function structure of a PID loop controller software is depicted in Figure 5.



Manipulated value high limit
Manipulated value low limit
Derivative action on
Derivative time
Integral action on
Sample time
Reset time
Proportional gain
Dead band width
Process value
Setpoint
Derivative component
Integral component
Proportionality component
Control deviation
High limit reached
Manipulated value
Low limit reached
PID_EXT_1
Determine control deviation
Stabilize controller
Determine proportionality component
Determine integral component
Determine derivative component
1-element FIFO
Controlled 1-element FIFO
Determine overall manipulated value
Maintain high limit of manipulated value
Maintain low limit of manipulated value

Figure 5. Function structure of a PID loop controller software

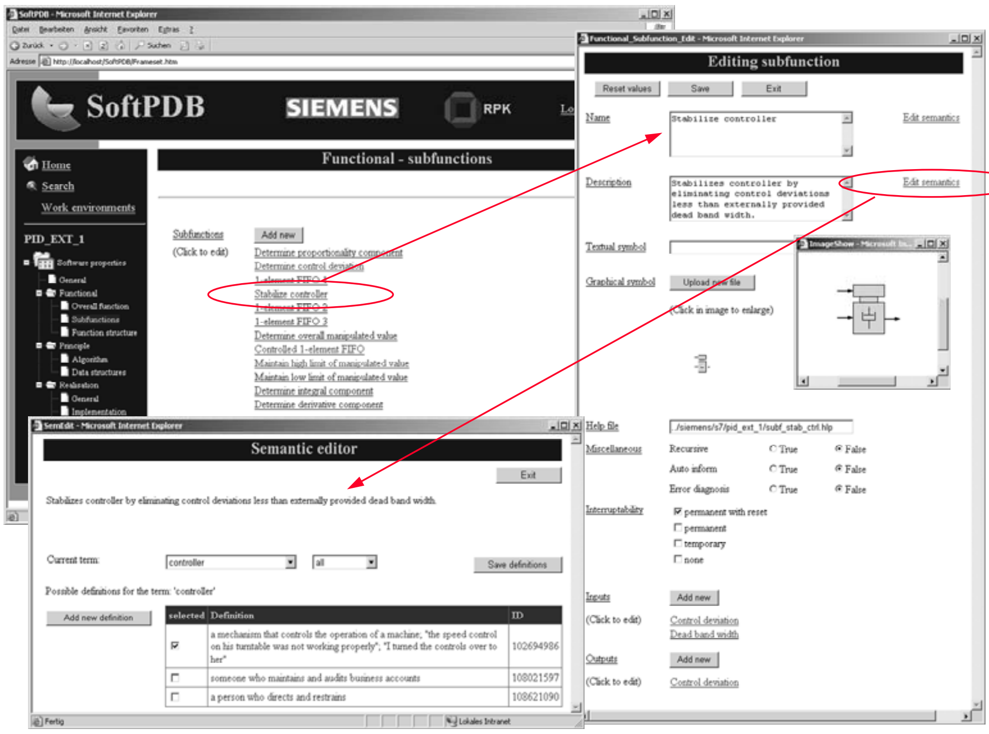
This function structure facilitates a structured functional specification, with significantly reduced complexity of sub-functions as compared to the overall function. This function structure increases understanding of mode of operation and behaviour of the software. For example, interrelations between reaching higher and lower limits of the manipulated value and the integral action become transparent. Specifications of the respective sub-functions indicate halting of the integral action, and state the concrete conditions. Thus, this structured specification facilitates evaluation of applicability and adaptability of the software component to a given task.

Depending on software component complexity, their functional analysis and specification can require considerable effort. However, methodical development of new applications implicitly produces significant part of the necessary information: Task clarification includes a definition of the overall function. Specification of sub-functions and their interconnections reduces complexity of the development task, and is required for distributed development (function structure). Potential procedure within a program is defined (flow chart), as well as the program interfaces (inputs and outputs). Therefore, integration of the proposed method into methodical software development processes can significantly reduce required effort for functional analysis and specification.

4. Prototypical implementation

The proposed method for functional specification of software components is part of the prototypical software component repository *Software Product Data Browser* (SoftPDB). Basis of this web-based application is a hierarchical structure of software product characteristics. The hierarchy results from analysis of the product environment in the corporate and application context, throughout the product life phases, and from abstraction to principle and functional aspects. Among others, the hierarchy

includes descriptions of algorithms and data structures, specifications of intended working environments (hardware and other software), organisational aspects of software development and distribution, and technical conditions specific to the different product life phases.
To identify potential solutions, elements and relations of function structures serve as main search criteria. With regard to potential ambiguities of task-specific function formulation using technical common speech, the repository features a semantic editor based on the WordNet lexical database [Fellbaum 1998]. Using this editor, users can provide definitions for terms used in designations and descriptions of overall functions and sub-functions, and their respective inputs and outputs (Figure 6).



Subfunctions [Add new]
(Click to edit)
Determine proportionality component
Determine control deviation
1-element FIFO 1
Stabilize controller
1-element FIFO 2
1-element FIFO 3
Determine overall manipulated value
Controlled 1-element FIFO
Maintain high limit of manipulated value
Maintain low limit of manipulated value
Determine integral component
Determine derivative component

Name: Stabilize controller — Edit semantics
Description: Stabilizes controller by eliminating control deviations less than externally provided dead band width. — Edit semantics
Textual symbol:
Graphical symbol: [Upload new file] (Click in image to enlarge)
Help file: ../siemens/s7/pid_ext_1/subf_stab_ctrl.hlp
Miscellaneous:
Recursive ○ True [✓ False]
Auto inform ○ True [✓ False]
Error diagnosis ○ True [✓ False]
Interruptability:
[✓ permanent with reset]
☐ permanent
☐ temporary
☐ none
Inputs [Add new]
(Click to edit)
Control deviation
Dead band width
Outputs [Add new]
(Click to edit)
Control deviation

Stabilizes controller by eliminating control deviations less than externally provided dead band width.

Current term: controller | all

Possible definitions for the term: 'controller'

selected	Definition	ID
✓	a mechanism that controls the operation of a machine; "the speed control on his turntable was not working properly"; "I turned the controls over to her"	102694986
☐	someone who maintains and audits business accounts	108021597
☐	a person who directs and restrains	108621090

Figure 6. Specification of sub-functions of a PID loop controller using the semantic editor

The semantic editor also enables the user to provide definitions for terms used in searches. Queries to the repository then do not compare terms, but definitions only. The semantic editor therefore facilitates effective use of synonyms and reduces the number of unsuitable matches.
Following identification of potential solutions, comparing their properties to requirements of the task allows evaluating their applicability. This particularly concerns best-case and worst-case software execution times in combination with different CPU types, determined by means of code analysis and CPU benchmarking.

5. Summary and conclusion

Re-use of design solutions can increase engineering design process efficiency and can contribute to the solutions' technological maturity. In the course of technical advancement, the importance of software components in technical systems increases in comparison to mechanical and electronic hardware. Methodical and IT support for standardised structured description of software products are currently not sufficient for internal re-use or electronic marketplaces.
This paper presents a web-based software component repository that can serve as an electronic data sheet for software components. As such, it can contribute to the electronic generation and continuous transfer of product data. The underlying hierarchy of software product characteristics is life cycle-

oriented and follows established methods of systematisation and abstraction from engineering design methodology. The repository can therefore serve as a comprehensive foundation for structured documentation of software, its functions, working principles, and other particularities throughout the product life. Specifically, the hierarchy of software product characteristics can structure and guide the compilation of requirements lists for software development.
To facilitate identification of solutions and evaluation of their applicability and adaptability with respect to given tasks, the repository employs the concept of task-specific functions. This concept from engineering design methodology has been adapted to consider specifics of software as a logical system. A process-oriented approach to method development with a focus on information conversion provided support for this method adaptation. The resulting method for functional specification facilitates the structured analysis and description of software components, by making transparent the underpinning logic and making manageable the complexity of the specification task.
The method for functional specification and the software component repository are a result from cooperation with industry in the context of automation technology. However, application in other domains is possible, as long as the relevant constraints are sufficiently similar.

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References

Fellbaum, C. (Ed.), "WordNet: An Electronic Lexical Database", MIT Press Cambridge, 1998.
IEC 61131-3, "Programmable controllers – Part 3: Programming languages", 2003.
IEC 61499-1, "Function blocks – Part 1: Architecture", 2005.
ISO 9000:2000, "Quality management systems – Fundamentals and vocabulary", 2000.
ISO/TS 16949, "Qualitaetsmanagementsysteme – Besondere Anforderungen bei Anwendung ISO 9001:2000 fuer die Serien- und Ersatzteilproduktion in der Automobilindustrie", Beuth Berlin, 2002.
Mueller, J., "Arbeitsmethoden der Technikwissenschaften", Springer Berlin, 1990.
Pahl, G., Beitz, W., Feldhusen, J. & Grote, K. H., "Konstruktionslehre", Springer Berlin, 2005.
Roth, K., "Konstruieren mit Konstruktionskatalogen. Bd. 1. Konstruktionslehre", Springer Berlin 2000.
Weigt, M., "An information-centred approach to the development and implementation of design methods", Proc. of the 15th International Conference on Engineering Design ICED 2005, Samuel, A. & Lewis, W. (Eds.), Melbourne, 2005.

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