Step by Step from Specification to Realization of an Electrochemical Microsystem

W. Süss†, K. Lindemann†, H. Eggert†, M. Gorges-Schleuter†, W. Jakob†, W. Hoffmann‡, R. Rapp‡  
Forschungszentrum Karlsruhe, †Institut für Angewandte Informatik, ‡Institut für Radiochemie  
Postfach 3640, D-76021 Karlsruhe, Germany  
Tel.: +49 7247 825722, Fax: +49 7247 862602, email: suess@iai.fzk.de

ABSTRACT

Subject of this paper is the step by step development of a microsystem. We started with the creation of a dynamical executable specification model. The next stage of development was characterized by substituting some simulated components by real ones. The result at this stage was a macro prototype of the microsystem. Replacing the macro by micro components the step by step development of the microsystem ended up in a real microsystem.

1 Introduction

The realization of microsystems is dominated by the fact that components still under development have to be put together. Because an entire system includes several different components, an early system integration is necessary in order to analyse the functional properties of the complete system as soon as possible. As a solution of this problem we choose the modelling of the functional dynamic system properties and the simulation of the system components and then replacing simulated components stepwise by real ones (see Figure 1).

We have used this approach for the realization of ELMAS, an electrochemical microanalysis system for the measurement of ion concentrations in fluids [1]. ELMAS consists in its final state of microsensors, micropumps, and a microcontroller for the system control.

2 Step by Step Development Using Statecharts

For the step by step development of ELMAS we used a method, which allows the creation of executable specifications. The method is based on extended finite automata, called Statecharts [2]. In this way the simulation of the complete system is possible starting with an abstract model and ending up with a monitor for controlling the real system components. The substitution of the simulated components can be done componentwise, so that the simulated components can be replaced by real ones according to their completion until only the overall control automata remains left. Thus we get a complete chain from specification to realization. An appropriate tool for this approach is Statemate (Statemate is a registered trademark of i-Logix, Inc.).

Figure 1: Stepwise development of a system
A Statemate model consists of three parts. The activity-chart describes the logical structure of the model, with the statecharts a behavioural description is given and the panel (user interface) controls the interaction between user and model. An example of a Statemate model is shown in Figure 2. For a better understanding we show in this example both, the activitychart and the statechart, on a schematic view only. To demonstrate the complexity of the Statemate model an example of a original statechart is shown in Figure 3.

In the activitychart the elements of the model are defined. The activitychart of this model is divided into two main parts. One part represents the microsystem and the other part represents the interaction between the system and the user. The part microsystem consists of the three blocks Controlling, Sensors and Actors. The part for the interaction between the system and the user is represented by the block named User-Interface.

The panel, the sensors and the actors are driven by the activitychart and the statecharts. Running simulations of the model checks and verifies the correct system behaviour.

The statechart is decomposed into three concurrent components. The upper component controls the interaction between the user and the system. The left component evaluates the sensor signals and the right component controls the

---

**Figure 2:** The parts of the Statemate model
micropumps. The main features of Statecharts, concurrency and hierarchy, can be seen in this example.

The panel is divided into two parts. The upper part is used for the interaction between user and system. It consists of three segments, the left one controls the actors, the middle one controls the sensors and the right one is used to show the system status. In the lower part of the panel the visualization of the sensor signals is done.

3 The Functional Concept of the Microsystem

The microsystem can among others be applied in the medical field (e.g. for the continuous blood control of patients) and will have the following main features: Integration of sensor arrays with different sensitivity for the simultaneous detection of different ions (e.g. pH, pNa); self control and self calibration of the system; handling of small fluid volumes (less than 20 µl); system architecture easy to modify; small size of the system; high precision; continuous measuring [3, 4].

The microsystem for the analysis of fluids consists of the components micropumps, the ion sensitive sensors (ISFET) and a microcontroller. Figure 4 shows the functional structure of the microsystem called „ELMAS“, an acronym for Electrochemical Microanalysis System.

The overall design is influenced by the behaviour of the ISFET-sensors showing some drift phenomena of the sensor signals. To compensate this time dependency two sensors
are used, a reference sensor and a measuring sensor, respectively. To provide the sensors with calibration medium a separate calibration reservoir is used, which can be seen in Figure 4. There are two major operating phases, the calibration phase and the measuring phase. During the calibration phase the calibration fluid is pumped over both sensors to compute a corrected sensor signal. In the next phase the measuring medium is pumped over the measuring sensor only. The difference signal of both the reference and measuring sensors is used to compute an accurate ion concentration value.

4 The Development of the Microsystem

In the early stage of development of the microsystem we created a dynamical executable specification model, based on Statecharts. We have seen this model above. The next stage of the development was characterized by substituting some simulated components by real ones. Figure 5 shows the workstation running the model and the connected components for the sensors and actors. At this stage with the exception of the sensors we have macro components to build a first prototype of ELMAS. These macro components are an electronic driven pipette and a commercial device for the acquisition of the sensor signals, which is called ECS-Meter. The pipette takes the part of the micropumps and the reservoir of calibration fluid. Figure 6 shows a part of the macro prototype, especially a macro flow through cell with two microsensors and the pipette. This macro prototype is still driven by the ELMAS model. The macro prototype was used as a first test-bed of the system under real conditions and this prototype was very useful for the further development of the chemical microsensors.

The next stage of the development is characterized by the stepwise substitution of the macro components by the micro components. Figure 7 shows the workstation running the model and the connected microsystem, consisting of an electronic modul and a fluidic modul. This version of the fluidic modul consists of chemical sensors, which are embedded in a microchannel, a reservoir of calibration fluid and micropumps. The control of the micropumps and the amplification of the sensor signals is done by the electronic modul, which was developed for the ELMAS microsystem. It is based on a Siemens 80C166 microcontroller and customized circuits. This electronic modul is connected via a serial interface to the workstation.

Three institutes of the Forschungszentrum Karlsruhe are participating in the microsystem development. The principles and materials for electrochemical microsensors are investigated at the Institute for Radiochemistry (IRCh). The Institute for Mikrostructural Engineering (IMT) fabricates the micropumps [5]. The Institut für Applied Computer Science (IAI) is responsible for the various information techniques, especially the development of the Statemate model and its communication with external components.
5 Conclusion

The development of any complex technical system requires a good understanding and asks for a specification of high quality. Very useful for this purpose are executable specifications; they can demonstrate system properties already in an early design stage and give a deep insight in the behaviour of the overall system. Thus the system requirements may be verified and design errors may be detected and eliminated earlier than by other approaches.

In this paper such a closed chain from specification to realization, giving us a lot of advantages, is described. The shortening of the time needed for development was one advantage. Other advantages are an easier communication between the participating partners based on the created dynamical executable specification model, the use of the macro prototype for the further development of the micro-sensors, and the early analysis of the overall system behaviour.

6 References


