

Requirements Elicitation Guide for Embedded Systems: An Industry Challenge

Luiz Eduardo Galvão Martins
Institute of Science and Technology
Federal University of São Paulo, UNIFESP
São José dos Campos, Brazil
e-mail: legmartins@unifesp.br

Jaime Cazuhiro Ossada
Technology College of Indaiatuba
Indaiatuba, Brazil
e-mail: Jaime.ossada@fatec.sp.gov.br

Anderson Belgamo
Methodist University of Piracicaba, UNIMEP
Piracicaba, Brazil
e-mail: anbelgamo@unimep.br

Bárbara Stefani Ranieri
Methodist University of Piracicaba, UNIMEP
Piracicaba, Brazil
e-mail: bsrnieri@unimep.br

Abstract—This paper presents GERSE, a guide to requirements elicitation for embedded systems – GERSE is a Portuguese acronym to *Guia de Elicitação de Requisitos para Sistemas Embarcados*. Despite the advances in the area of embedded systems, there is a shortage of requirements elicitation techniques that meet the particularities of this segment. The contribution of GERSE is to improve the capturing process and organization of the embedded systems requirements. The proposed guide was based on a field research with Brazilian developers to find out the state of practice in embedded systems requirements. GERSE had been tested in a case study and had been evaluated by embedded systems engineers. A tool called *ZAKI* was developed to support GERSE and is also presented in this paper.

Keywords - *Embedded Systems; Requirements Elicitation; Requirements Template.*

I. INTRODUCTION

Currently, the Embedded Systems (ES) projects have been created for a lot of purposes and they are an area with several aspects to be explored. The presence of ES has increased in the last years and they have become almost ubiquitous in segments as industry, commerce and residences [4]. The developed software for ES is becoming more and more complex and sophisticate, of course this increased sophistication has a strong influence in system requirements elicitation and management. In ES context, more than 50% of the problems occur after the system is delivered to the customer [10][15]. However, the described problems are not implementation mistakes, but most of them are requirement issues emerged during the system conception.

The ES are present in our daily life and the trend is to increase in large scale in the next years. Currently, billions of processors have been built a year to supply the ES market [2]. Taking such context under consideration, we present GERSE in this paper as a guide to drive the requirements elicitation for embedded systems. GERSE will support ES

developers to create safer, trustworthy, complete, and correct ES using requirements engineering as a basis.

The ES development has grown a lot in the last years, but the industries still have serious problems to define patterns and templates to adequately address the particularities of the requirements definition of ES. The consolidation of the good practices that effectively support the demands of the ES development process is still a great challenge to industry.

This paper is organized as follows: in section two, related works involving requirements engineering to ES are commented; in section three, the phases and activities proposed by GERSE are presented; section four presents a case study and the evaluation of the GERSE, performed by ES engineers; section five presents a software tool to support GERSE; and finally, in section six, some conclusions and future works are pointed out.

II. REQUIREMENTS ENGINEERING FOR EMBEDDED SYSTEMS

While embedded software is becoming more complex the ES engineers are asking the software engineering community techniques, methods and tools which can help them to improve software quality for ES. On the other hand, software engineering community is recognizing the necessity to adapt the existing methods and to offer new ones to effectively support the particularities of the ES area [15][16][17].

Based on the literature review and the interaction to the ES professionals it is possible to detect just few requirements engineering methods, techniques and tools to address the ES particularities [1][7][9]. For instance, the software development in the automotive industry is a field that brings a great challenge to software engineering, where real time and security requirements come together. For the automotive ES to reach their goals, it is necessary that software control functions work correctly according to strict requirements [5].

Beyond the automotive industry, the ES projects have become larger following the electronic components evolution and consequently making new challenges to requirements engineering. A great challenge is to produce ES with high quality and also supply the market before the system becomes obsolete. As discussed by Cheng and Atlee [8], the development teams must use software engineering techniques and processes to improve the productivity of the developers and the quality of the incoming software. The requirements engineering processes [12][14] help the stakeholders to define what they really need, allowing the suppliers to clearly understand the requirements being implemented in the ES. In this requirements definition process, several professionals with different skills collaborate, such as: users and customers, specific domain experts, marketing specialists, project managers, electrical engineers, mechanical engineers, software engineers and others. For this group, the requirements engineering can offer several benefits, as follows: support to agreements and project planning, shortening the development schedule, offering a consistent basis for deadlines estimation, a baseline for validation and verification, and trustworthy artifacts to drive the ES development.

In Broy's work [5], two phases are suggested to run requirements elicitation:

- (i) Pre-phase: the first approximation of the product to be developed; during this phase the strategies and the position of the product in the marketplace are defined. The goals and marketing issues are planned and a document must be written reporting the product constraints and possible alternatives.
- (ii) Main phase: based on the results from the pre-phase an agreement among the stakeholders must be done. This agreement is an extensive specification of the technical requirements of the product.

As discussed in [5][15], the conventional methods used to perform requirements engineering are incomplete and do not adequately address the particularities and necessities of ES. The requirements engineering to specify electronics, automotives and other devices that need ES demand adjustments. That is the main point discussed in this work and the motivation to propose GERSE.

To propose the requirements elicitation guide for ES presented in this paper, a literature review about requirements engineering related to many aspects of ES was performed. This review covered the period from 1997 to 2012.. Most of the reviewed works pointed out the issues and difficulties at the early stages of the ES development [3] [6] [13] [19], however, it was not found any suggestion about specific methodologies for capturing and defining requirements, or even a guide to refine and transform the high level requirements - close to customers and users - to technical requirements - close to ES engineers.

III. GERSE: A PROPOSAL FOR A REQUIREMENTS ELICITATION GUIDE

In GERSE elaboration, a field research with 53 professionals that worked with ES in the Brazilian market was initially performed. The goal of this field research about requirements elicitation of the ES was to know the state of practice in Brazil. Therefore, professionals who worked in several segments using ES were invited, most of them being professionals working in industries in São Paulo state. The main segments covered in this research were: automotive systems, industrial automation, home appliance, domotics, medical devices, telecommunication and entertainment.

After the organization and analysis of the field research results, a study about IEEE Std. 830-1998 recommendation [11] and *Volere template* [18] was performed. The *IEEE Std. 930-1998* recommendation suggests how to organize software requirements proposing several generic specification templates. The *Volere* template is a document that suggests a detailed framework to document and organize software requirements. Both *IEEE Std. 830-1998* recommendation and *Volere* template are very known by the requirements engineering community, but they are generic guides for requirements elicitation.

Based on these three elements (*IEEE Std. 830-1998*, *Volere* template and the field research results) groups of activities that compose GERSE were proposed, such set of activities was organized in a way to support the ES engineers to better capture and specify ES requirements.

The main goal of the proposed guide is to help ES engineers during the requirements elicitation process. GERSE leads ES engineers during the elicitation process offering a set of activities that addresses the ES main features. Using GERSE, ES engineers can manage the requirements elicitation process in an organized way. The proposed guide helps the requirements definition allowing its complete specification for products based on embedded technology. GERSE is divided into two phases, named pre-phase and main phase, which are organized in seven categories. These categories are organized in 46 activities, which are responsible to generate the artifacts that will compose the ES requirements. Each activity produces at least one artifact that can be both a document describing a specific feature of the product or a diagram modeling any specific feature. The activities of the pre-phase will help the ES engineers to make the transition from the high level requirements to technical requirements. Figure 1 shows a GERSE overview presenting the categories proposed to each phase.

GERSE is divided into two phases: pre-phase e main phase. During the pre-phase the activities were gathered into three categories: Context Organization, Stakeholders Definition and High Level Requirements Elicitation. In the main phase, the activities were gathered into four categories: Definition of Hardware Requirements, Definition of Software Requirements, Identification of Quality Metrics and Identification of Production Requirements. Considering

the activities of all categories GERSE offers 46 activities to perform a complete requirements elicitation of the ES. Each category has specific goals supported by activities that should help the ES engineers to produce useful artifacts to compose the requirements specification of the ES to be developed.

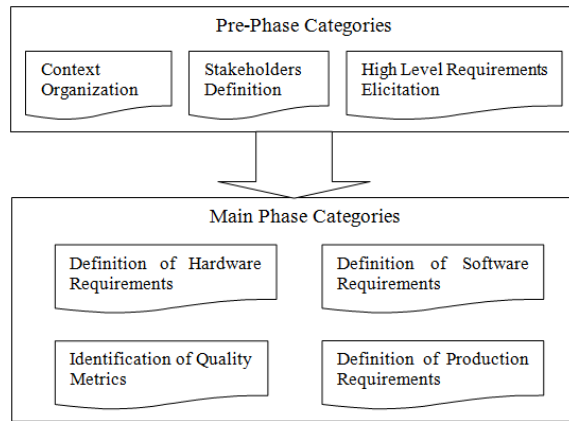


Figure 1. Phases and categories supported by GERSE.

During the pre-phase, the requirements that will help the ES engineers to understand the system to be developed are captured, such requirements define the system basic features, purposes, and goals. The final artifact obtained using GERSE set of activities is a high level requirements specification, which defines all the ES characteristics, referring to mechanical, electrical and functional aspects plus the system cost overview, prototype model and all functional and non-functional requirements. It is important to observe that ES non-functional requirements are different from those usually managed in conventional systems. For example, energy consumption is an ES specific non-functional requirements.

When the pre-phase requirements are gathered, it is necessary to transform them into technical requirements, such transformation will enrich the requirements with more details. In this process, the category “High Level Requirements Elicitation” has a very important role because the requirements obtained from this category will be the requirements core to be transformed into technical requirements. After all activities suggested in GERSE are performed, the ES engineers gather a large set of functional and non-functional requirements that specify the main features of the ES. The cost to gather such requirements documentation is low when GERSE activities are followed by the ES engineers. This documentation facilitates the project development in parallel ways: one team developing the hardware and other team developing the software, turning the ES development faster to answer the time to market.

IV. CASE STUDY AND GERSE EVALUATION

In this section, a case study is presented using GERSE. The guide was instantiated to produce the requirements elicitation of a digital chess clock used in professional chess tournaments. The purpose of this experience was to evaluate GERSE in a real situation choosing a specific product and eliciting ES requirements that must control such product. The case study shows some artifacts generated using GERSE during the requirements elicitation process.

Table 1 presents the results gathered from the activities performed in the category “Stakeholders Definition”. The identified stakeholders include: commercial department, marketing department, components suppliers, chess referees, other manufacturers, chess players, and hobbyists. The evolution degree and influence degree on the project were defined for each type of stakeholders.

TABLE I. RESULTS GATHERED IN THE ACTIVITIES FROM THE CATEGORY “STAKEHOLDERS DEFINITION”

Activity	Output Artifacts
Definition of key stakeholder	<p>Commercial Department: Involvement level: low Influence on project: Approval of final costs.</p> <p>Department of Marketing Involvement level: High Influence on project: approval of the characteristics of packaging, reliability, performance, usability and action buttons.</p> <p>Component manufacturers and suppliers Involvement level: High Influence on project: collaborate by providing technical specifications of the components to engineers to make better use of components to be used in product development.</p>
Determine domain experts stakeholders	<p>Chess referee Involvement level: High Influence on Project: help understand the official rules of chess game according to the FIDE (World Chess Federation).</p>
Identify stakeholders against the project	<p>Competitors' manufacturer Involvement level: High, because the clocks available on the market by manufacturers are used as references for comparison of new product.</p>
Characterize User Profiles	<p>Professional chess players Profile: Users accustomed with digital chess clock available in the market. Use the clock to study and compete.</p> <p>Hobbyists Profile: users more accustomed to analog clocks. Use the clock to study, and eventually in competitions.</p>

Figure 2 presents a suggestion for the design of the case, as well as the keys and the chess clock display, this prototype is resulted from the activities in the category “High Level Requirements Elicitation”. This prototype was based on market analysis and a requirements elicitation process performed with professional chess players, which pointed out the main functions that a digital chess clock has to offer for the users, especially for those who use it in professional tournaments.

The complete requirements specification of the digital chess clock and GERSE documentation were sent to four ES engineers to evaluate the proposed guide, the evaluation was performed based on a survey. The ES engineers' expertise was in automotive systems, medical devices and entertainment areas. The survey was composed by twenty one questions based on Likert's scale [20]. The case study results, GERSE documentation and the survey were e-mailed to the ES engineers. The answers to the survey allowed a realistic evaluation of GERSE viability.

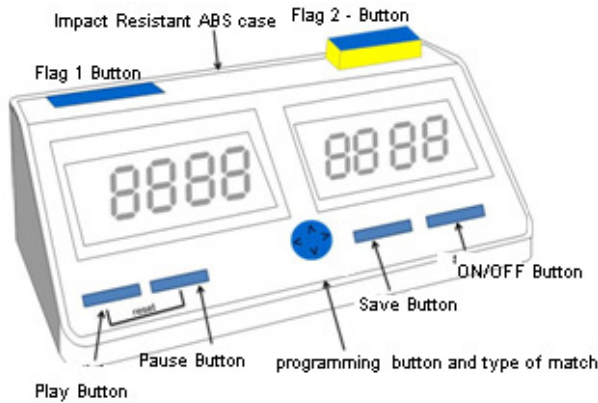


Figure 2. Initial product prototype showing the main functions - gathered in the activities performed from the category "High Level Requirements Elicitation".

Table II presents the results gathered in the activities performed from the category "Definitions of Hardware Requirements". In this table, the main hardware requirements of the digital chess clock are presented, which specify the sensors, interaction displays, keys, external communication interface, hardware interruptions and microcontroller necessary to build the product. Considering the unique aspects of this project it was not necessary to specify actuators.

TABLE II. RESULTS GATHERED IN THE ACTIVITIES FROM THE CATEGORY "DEFINITION OF HARDWARE REQUIREMENTS"

Activity	Output Artifacts
Determine sensor	<p>01 Humidity sensor Function: continually check the internal moisture of the product to avoid damage to the components. Type: analog.</p> <p>01 Temperature sensor Function: check the value of the internal chassis temperature, to ensure that it will not exceed the working temperature range of the internal components. Type: analog.</p>
Delimit the actuators	Not applied to this product.
Clarify user interaction	<p>02 LCD graphical with 128 x 64 Function: display the playing remaining time for each player (update the display in real time).</p> <p>01 Buzzer Function: warning to the end of settings, end of the game and battery low level.</p>

Characterize hardware interruptions	<p>Temperature Range Function: sound and light warning should be issued if the temperature is outside the ranges of acceptable values.</p> <p>Humidity range Function: sound and light warning should be issued if the humidity is outside the ranges of acceptable values.</p> <p>Battery Function: sound and light warning should be issued if the battery low level.</p> <p>Pause Function: by pressing the "pause" the time count both counters should be frozen.</p>
Identify the action buttons	<p>02 on/off switch with lock Function: activation of the stop watch time player who makes the move (and freezing the timer player that does the move).</p> <p>01 Button type joystick Function: button for programming should have 4 positions (left, right, up, down) and a central (enter), for control and navigation mode for programming.</p> <p>04 Buttons without locking Function: buttons to pause, start, save programming, turn off and on the clock.</p>
Specify the memories	<p>01 PROM memory Function: storage modalities of game time.</p> <p>01 Flash memory Function: store setup(variable) of types of playing time.</p>
Define external communication ports	<p>USB Port Function: connection to external board for automatic storage of moves.</p>
Fix component requirements	<p>AC / DC Adapter Function: battery charging</p>
Specify the requirements for layout of controller board	The layout of the printed circuit board to be double sided to contribute to miniaturization of the enclosure.
Defining the parameters of legacy hardware	Not applied to this product.
Demarcating the parameters of special COTS	Not applied to this product.
Identify microcontrollers	PIC PIC18F4550-I/P 32 KB/2048 RAM 35 I/O microcontrollers with USB support.

All ES engineers evaluated GERSE as a useful guide for ES requirements elicitation stating that such guide is easy to use and contributes to increase the ES development quality. Table III shows GERSE general evaluation results. It is possible to observe that GERSE was well evaluated, especially the aspects concerned to clearness, easiness of use and the contribution to improve the quality of requirements elicitation. The ES engineers considered the guide easy to use and it supports their requirements elicitation necessities. The completeness is an issue that must be improved in GERSE.

TABLE III. GERSE GENERAL EVALUATION

Questions	Totally agree	Partially agree	Partially disagree	Totally disagree
The presented guide is clear enough to be used in an embedded systems design for small and medium businesses.	50%	50%	0%	0%
The presented guide is complete and meets the needs of embedded systems projects for small and medium businesses.	50%	25%	25%	0%
Would adopt the presented guide for requirements elicitation on future projects.	50%	25%	25%	0%
The presented guide is easy to use.	50%	50%	0%	0%
The presented guide contributes in improving the quality of embedded systems development.	50%	50%	0%	0%
The presented guide meets your needs requirements definitions in embedded systems projects.	50%	50%	0%	0%

V. ZAKI: A COMPUTATIONAL SUPPORT TO GERSE

The adoption of any software process can be facilitated by the use of computer support. In this sense, a tool called Zaki [21] was developed, to support GERSE activities and the requirements elicitation process for embedded systems.

Zaki tool is divided into two modules, according to GERSE phases (pre-phase and main phase), supporting activities like requirements elicitation, analysis and management for embedded systems. Zaki tool was developed using .NET platform (C# language) and the SQL Server database.

During the pre-phase, Zaki tool supports functionalities related to manage information about project guidelines and main product features, development organizational impact and target audience. During the main phase, Zaki tool is divided into three modules: Definition of Hardware Requirements, Definition of Software Requirements, and Identification of Quality Metrics.

Specifically related to Definition of Hardware Requirements, Zaki tool converts high level requirements to technical ones, allowing the definition of sensors, actuators, memory, microcontrollers, legacy hardware and other requirements associated to hardware components. Besides, it is possible to choose COTS (Commercial Off-The-Shelf) to be used in the embedded systems. Figure 3 presents a user interface of Zaki tool responsible to record actuators related to the embedded system project.

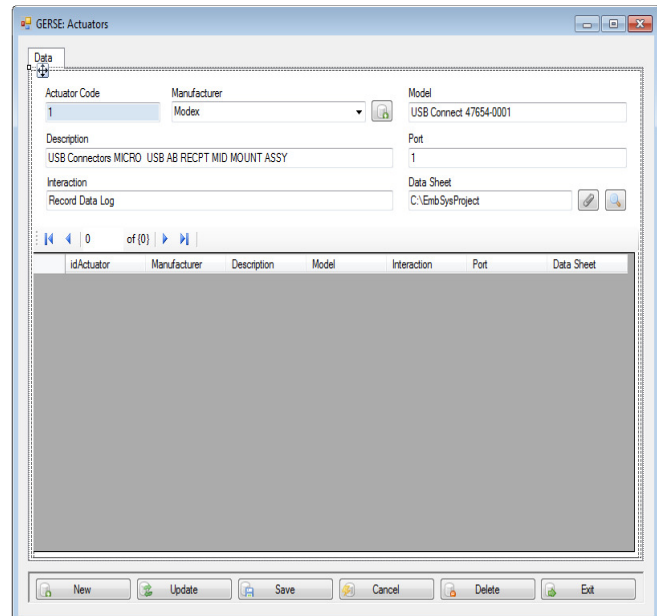


Figure 3. User interface of Zaki tool to manage actuators.

Aiming to perform a feasibility study of Zaki tool, three requirements engineers - with over two years of experience in the area - were asked to perform the requirements elicitation and specification for an embedded system to a data logger device. The main goal of such device is monitoring and collecting environmental data, including temperature, atmospheric pressure, humidity, rainfall, wind speed, and others.

TABLE IV. ADDRESSING QUESTIONS TO THE ELICITATION PROCESS SUPPORTED BY ZAKI

Questions	Totally agree	Partially agree	Disagr
The tool meets the goals of the requirements elicitation process for embedded systems.	100%	0%	0%
The tool facilitates the process of requirements elicitation, assuring quality of project and time reduction.	100%	0%	0%
The tool organizes information about the project and ensures an efficient requirements elicitation process.	25%	75%	0%
The tool supports a complete requirements elicitation process, ensuring the completeness of the project goals.	100%	0%	0%

The evaluation was performed by the filling of a questionnaire with 15 questions - 13 objective questions and 2 personal observations. The goal of evaluation was to analyze the use of Zaki tool to identify improvements and non compliances.

According to Table IV, the requirements engineers were unanimous in stating that the tool supports the requirements elicitation process, facilitating and reflecting in time savings and quality of the embedded systems project. However, interfaces improvements must be performed to facilitate the usage of Zaki tool.

VI. CONCLUSION AND FUTURE WORK

GERSE proposed activities support engineers guiding ES requirements elicitation and specification, which help them to produce an organized, easy to understand and complete requirements document. According to the evaluation performed by ES engineers, GERSE reaches the goal of being itself a consistent guide for ES requirements elicitation. One of this work's relevant contribution is to narrow the gap between Software Engineering – specifically concerned to Requirements Engineering - and ES engineering. The requirements elicitation for any kind of system is not a trivial job. Particularly for ES, there are a lot of specific issues to be managed, for instance: real-time requirements, energy consume control, hardware constraints – sensors, actuators, memory and microcontrollers – short window of *time-to-market*.

GERSE evaluation performed by ES engineers with expertise in several areas of application, as automotive, medical devices and entertainment, pointed out that the guide is clear and easy to understand. But the evaluation also reveals that some aspects can be improved such as GERSE completeness, specially the activities concerned to quality metrics and production requirements. These issues are going to be treated in future works. In general, GERSE was considered satisfactory contributing to fulfill the existent gap in the early stages of an ES project. GERSE contributes to decrease the occurrence of faults, errors and mistakes that are very common during the ES requirements capturing. A mature requirements elicitation process can be reached using GERSE, which supports the transition of high level requirements to technical ones. This paper also presented *Zaki*, a tool to support GERSE adoption, since it can assist ES engineers to better manage the requirements gathered when GERSE is running.

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