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Development Practices of Embedded Systems: SMEs in SEE countries

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Abstract

Background: Embedded systems are evolving in their use based on the increased trend of merging software with hardware appliances. The market for the embedded systems development is rapidly increasing and this is one of the possible new markets for software firms striving for new competitive advantage. **Objectives:** The goal of the paper is to explore embedded systems development practices of Croatian firms and compare them with the practices of the firms from South Eastern European (SEE) countries. **Methods/Approach:** The survey was conducted using the sample of SME software firms and the data on embedded systems development practices have been analysed. Practices of Croatian firms were compared with practices of other firms from SEE countries. **Results:** Results of the survey revealed that in comparison to their counterparts from SEE countries, Croatian firms involved in embedded systems development utilise cutting-edge technology and processes to a lower extent. **Conclusions:** Cutting-edge technology and processes are prerequisites for attaining the level of productivity in software production that is sufficient to ensure maintaining cost competency. However, SMEs are yet to fulfil their market potentials.

Keywords: embedded systems, development, FP7, project, SMEs

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Introduction

Embedded systems are both the long-time known, and the currently highly propulsive part of technology. They are defined as computer systems forming a part of a larger system, performing specific function. One of their characteristics is that they are combination of mutually interconnected hardware and software. Despite

that interconnectedness, the embedded systems' software development is a well-defined market segment (Schlett, 2000). All statistics and predictions point to rapid future increase in their use, both in quantity (BCC Research, 2012; Lakka et al., 2013) and versatile areas of application (Jerbić, 2007).

According to Ilgin et al. there are strict necessities related to the target system operation containing safety and real-time operation within the area of embedded systems design and development (Ilgin et al., 2010). Firms that compete at the market of development and implementation of embedded system has to strive for excellence in terms of software quality, that is attained through the use of formal development practices, variety of system platforms used, broad range of software/hardware integration practices and serious approach to performance evaluation and performance optimization.

In this article we concentrate onto national use of embedded systems' development practices of SME software firms that compete in the market of embedded systems, analyse it and compare with the corresponding use in Greece and Serbia. In order to measure embedded systems' development practices a survey on the sample of SME software firms was conducted. Following research questions were defined for the purpose of the article:

- RQ1 – What embedded system development issues are used among SMEs?
- RQ3 – What software/hardware integration practices are used among SMEs?
- RQ3 – What performance evaluation and performance optimization are used among SMEs?

This research framework aims to complete the empirical outlook to the embedded system development practice in SME software firms in selected SEE countries. These research questions are relevant both to the IT industry and IT academics because embedded system systems become increasingly important new market, and there is a rising call for gaining as much knowledge as possible on current practical issues. Moreover, it is important to develop tools available to SMEs that would increase quality of embedded systems and thus allow them to compete to larger firms. SME software firms that target embedded systems market needs to adapt to the growing quality standards that would be best accomplished by using technical methodologies, additionally an open and customisable toolset.

The article is organised as follows: data collecting methodology was described in the second section; third section lists some of the collected results, while fourth section concludes the article and lists some perspectives.

Information and communication technology

Through the increasing popularity of the global network Internet began the rapid growth of the information and communications technology (ICT) sector. That was in the early 1980s. Internet was also a main infrastructure for commerce (e-commerce) and communication. The major portion of an ICT firm investment is in the field of research and development (R&D), nevertheless financing such expenditure is difficult in a competitive marketplace. Investment decisions are often related to the availability of cash flow, regardless of the industry (Aoun et al., 2008). There are many benefits related to usage of the ICT, in addition, their quality usage save money and/or time. ICTs have as their main features the application of knowledge, and they also generate new knowledge. Ollo-López et al. point out that ICT take on a main role in the economy transformation process in addition to constituting a vital source of competitiveness for the companies. Use of ICT seems to increase the level of competitiveness in the companies (Ollo-López et al., 2012). Information and

communication technology (ICT) has improved the quality life of the citizens and enhanced the growth of the global economy. Ti has brought new ways of creating livings for individuals (Doong et al., 2012). According to García-Villaverde et al. the ICT industry is shifting rapidly in reaction to technology and market developments, competition and regulation change (García-Villaverde et al., 2011). Internal factors in corporations are crucial for adopting and using ICT in order to increase business performance and competitiveness (Pejić Bach et al., 2013). The turbulent times are the main characteristics of the ICT industry (Crnković, 2013).
According to Grasser one of the fastest growing sectors in the ICT are embedded technologies. There are still open fields with many business occasions. Practically all products are associated with embedded systems components in order to reach the market (Grasser, 2007). Furthermore, due to their ability to widely distribute power through their small, inexpensive and ubiquitous characteristics, embedded systems compromise larger opportunities and worries. They are some kind of the extension of ICT, which deals with large networks of small computing devices (LePoire, 2004).

Methodology

Survey on embedded system development practices was conducted as one of the activities of FP7 project, MODUS-Methodology and supporting toolset advancing embedded systems quality (Project No.: 286583). Goal of the project is to provide pragmatic and viable solutions in terms of a set of technical methodologies and open and customisable toolset that will permit SMEs to substantially advance their positioning within the embedded-systems development market. An open and customisable toolset with a set of technical methodologies, evolving embedded systems quality when using Formal Description Techniques (FDTs) will be developed and validated. It was decided that primarily firms that provide embedded system for automotive, avionic and telecommunication industries will be targeted. Members of the MODUS project developed questionnaire used in the survey.

Survey was conducted on the sample of SME software firms in Croatia and selected SEE countries (Greece, Serbia, and Bosnia and Herzegovina). Target group of firms were SMEs specialising in the development of embedded systems in different industrial sectors (avionics, automotive systems, telecommunications and other). For the purpose of the survey, random sample approach was employed since embedded systems are developed by the limited number of software firms. In Croatia, firms registered for software development were identified using Croatian Company Directory (http://www1.biznet.hr/HgkWeb/do/extlogon). Firms that registered Computer programming, consultancy and related activities (Nace 2007 Code: J62) as primary business activity and with number of employees from 1 to 250 were selected using Advanced search option. Total number of 1456 firms was selected. Random sample of 600 firms were selected, and 9 firms participated in the survey. In the same time 20 firms from other SEE countries also participated in the survey. Due to the small number of firms that participated in the survey, this research is considered as a preliminary research that will be followed by more comprehensive research in the future. When sample size considerations were at least partly attained, chi-square test has been applied in order to test differences between Croatian and other SEE countries' firms.

Table 1 represents number of employees involved in embedded SW/HW development in the sample companies. Croatian firms involved in embedded systems software development are smaller measured in terms of number of employees compared to total sample firms. More Croatian firms have 1 do 10 employees involved in SW/HW development (89 % firms) compared to total sample

(62 % firms). On the other side, in the total sample there is 28% of the firms with more than 10 employees involved in SW/HW development, while in Croatian sample, only 11% of firms employ that number. Chi-square test revealed that the difference in structure of total sampled firms and Croatian sampled firms in number of employees involved in SW/HW development is statistically significant at 1% (χ^2=18.713, p-value=0,000).

Table 1
Number of employees involved in embedded SW/HW development in the sample companies

No. of employees	Total sample (N = 29)	Croatian sample (N = 9)	Total sample, %	Croatian sample, %	Chi-square	P-value
1-10	18	8	62	89	18.713	< 0.001***
11-50	4	0	14	0		
51-150	4	1	14	11		

Source: Authors' survey
Note: *** statistically significant at 1% level

Areas of application are broad for software firms that develop and implement embedded system, and there are differences among Croatian software SME firms and other firms from selected SEE countries (Table 2). None of the Croatian firms develop software for avionics industry, but ratio of Croatian firms that develop software for automotive and telecommunication industry is larger compared to the ratio of selected SEE countries. Other areas of application for which the firms/organizations develop embedded system are defence, control, technical automation, finance, banking, medical care, camera motion control, space, video monitoring, and video surveillance. Among those, Croatian firms mentioned camera motion control, medical software and banking. Chi-square test revealed that difference between Croatian firms and other countries' firms is statistically significant only for automotive industry at 1% level (χ2 = 12.715, p-value = 0.000), avionics industry at 10% level (χ2 = 3.046, p-value = 0.080) and other industries at 1% level (χ2 = 8.365, p-value = 0.004).

Table 2
Areas of applications for which the firms/organizations develop embedded system

Areas of applications	Total sample	Croatian sample	% total sample	% Croatian sample	Chi-square	P-value
Avionics	1	0	3%	0%	3.046	0.080*
Automotive	9	5	31%	56%	12.715	0.000***
Telecommunication	11	4	38%	44%	0.744	0.388
Defence	4	1	14%	11%	0.411	0.521
Control	7	2	24%	22%	0.113	0.737
General purpose software development	15	5	52%	56%	0.322	0.570
Other	12	2	41%	22%	8.365	0.004***

Source: Authors' survey
Note: *** statistically significant at 1% level, * statistically significant at 10% level

Results

Embedded system development issues

Embedded system development issues are presented in Table 3, and refer to: (1) Modelling languages used for software development, (2) Testing the software developed by the company, (3) Generating the source code, (4) Coding standards/recommendations that firms use for software development, (5) Verification of the designed models, and (6) Target code of the firms.

Modelling languages used for software development. The most used modelling language for software development is UML that is used among 52% of the firms from the total sample and 44% of the Croatian firms. None of the Croatian firms use Simulink/Stateflow, which is used among 15% of other SEE countries' firms. Other modelling languages used for software development were custom solution (Croatian firm), SSA, Sybase Power Designer, and MERISE. Chi-square test revealed that difference between Croatian firms and other countries' firms is statistically significant for the usage of Simulink/Stateflow, no modelling language and other language usage.

Testing the software developed by the firm. In most of the cases, sample firms test the software developed by the firm with manual test cases, while automated test cases and specific tools are used to the lesser extent. Specific tools used for testing the software developed by the firm were Test Link, Selenium, Test Complete, gMeter, Custom tools, IBM Rational Functional tester, IBM Rational Performance tester and MS Visual Studio TFS. There are no significant differences among Croatian and other SEE countries' firms, except for the testing with specific tools.

Generating the source code. Firms from both Croatia and total sample generate the code in most of the cases manually. Although smaller number of firms is using automatic code generation; it is interesting to know which practices were used. Automatic code generation using commercial code generator used were Microsoft Visual Studio, Interpreting models instead of generating code, Power Designer + Eclipse (Croatian firm) and 2E (Croatian firm).

Coding standards/recommendations that firms use for software development. None of the Croatian firms is using coding standards/recommendations for software development, while other SEE countries' firms are using MISRA C and CERT C Secure Coding Standard. Other coding standards recommendations that firms use for software development were Sun Microsystems, MSDN C# Usage Guidelines. ("Design Guidelines for Class Library Developers" - Microsoft), Coding Standard: C# - Philips Medical Systems, LabVIEW Development Guidelines, Java development community standard, Custom coding convention, Oracle code conventions for the Java programming language (Croatian firm), ECSS, MISRA C-based internal code conventions, and All-In-One Code Framework Coding Guideline.

Verification of the designed models. More firms from the other SEE countries use tools for verification of the designed models compared to Croatian firms. Tools for verification of the designed models were Enterprise Architect, and Internal, project-based tools. Difference among Croatian and other firms is statistically significant at 1% level.

Target code of the firms. Target code of the firms refers in most of the cases to language C (C, C#, C++, and Java. Other target code of the firms were php, Ruby, Python, LabVIEW, VB.NET, Javascript (Croatian firm), SQL + SQLJ (Croatian firm), VB6+ VB.NET + ASSEMBLY (Croatian firm), and FORTRAN. There are some differences between Croatian firms and other countries' firms, and statistically significant difference has been found for C, C# and other target codes.

Table 3
Embedded system development issues used by the sample firms

	Total sample (N = 29)	Croatian sample (N = 9)	Total sample, %	Croatian sample, %	Chi-square	P-value
Modelling languages used for software development						
UML	15	4	52	44	1.282	0.258
Simulink/Stateflow	3	0	10	0	10.526	0.001***
No modelling language	10	0	34	0	9.778	0.001***
Other	4	0	14	0	15.054	0.000***
Testing the software developed by the company						
Yes, with manual test cases	23	7	79	78	0.030	0.862
Yes, with automated test cases	12	3	41	33	1.373	0.241
Yes, with specific tools	5	3	17	33	6.827	0.009**
Generating the source code						
Manually	23	8	79	89	3.720	0.054**
Automatic code generation using custom code generator	6	3	21	33	3.653	0.056**
Automatic code generation using commercial code generator	7	1	24	11	5.853	0.016**
Coding standards/recommendations that companies use for software development						
MISRA C	3	0	10	0	10.526	0.001***
CERT C Secure Coding Standard	1	0	3	0	3.046	0.081*
Other	8	0	28	0	32.558	0.000***
Verification of the designed models						
Yes	8	1	27	11	8.317	0.003***
No	21	8	73	89		
Target code of the companies						
C	13	0	45	0	58.065	0.000***
C#	14	2	48	22	14.857	0.000***
C++	13	4	45	44	0.020	0.887
Java	10	4	34	44	2.102	0.147
php	5	1	17	11	1.495	0.221
Python / Ruby	4	1	14	0	0.411	0.521
Other	7	0	24	0	27.273	0.000***

Source: Authors' survey
Note: *** statistically significant at 1% level, ** statistically significant at 5% level, * statistically significant at 10% level

System platforms are broad for software firms that develop and implement embedded system, and there are differences among Croatian software SME firms and other firms from selected SEE countries (Table 4). Croatian firms used only some system platforms such as Windows, Linix and Unix. Other firms used much more system platforms and the most used are Windows, Linux, Android, Windows Mobile. Chi-square test revealed that difference between Croatian firms and other countries' firms is statistically significant for Windows platform, which is used the most, at 1% level ($\chi 2 = 15.672$, p-value = 0.000), for Macos at 1% level ($\chi 2 = 9.205$, p-value = .002), for Windows Mobile at 5% level ($\chi 2 = 6.095$, p-value = 0.014), for Android at 1%

level ($\chi 2$ = 8.365, p-value = 0.004) and for Free BSD at 5% level ($\chi 2$ = 4.916, p-value = 0.026).

Table 4
System platforms used by the sample companies

System platforms used	Total sample (N = 29)	Croatian sample (N = 9)	Total sample, %	Croatian sample, %	Chi-square	P-value
Windows	26	6	90	67	15.672	0.000***
Linux	21	6	72	67	0.590	0.442
FreeBSD	1	1	3	11	4.916	0.026**
Unix	8	3	28	33	0.590	0.442
Macos	8	1	28	11	9.205	0.002***
Solaris	3	1	10	11	0.053	0.818
RTEMS	1	0	3	0	3.046	0.080*
Android	12	2	41	22	8.365	0.004***
Blackberry OS	2	0	7	0	7.254	0.007**
iOS	6	2	21	22	0.030	0.862
Embedded Linux	4	0	14	0	15.054	0.000***
Palm OS	1	0	3	0	3.046	0.080*
Symbian	4	0	14	0	15.054	0.000***
WebOS	1	0	3	0	3.046	0.080*
Windows mobile	11	2	38	22	6.095	0.014**
Texas Instruments SYS/BIOS	1	0	3	0	3.046	0.080*
Xtratum	1	0	3	0	3.046	0.080*

Source: Authors' survey
Note: *** statistically significant at 1% level, ** statistically significant at 5% level, * statistically significant at 10% level

Software/hardware integration practices

Software/hardware integration practices presented in Table 5 refer to: (1) Communication interfaces used by the software developed, (2) Target processors for the software developed, (3) Process for best matching Hardware/Software co-simulation, and (4) Performance requirements for hardware.

Communication interfaces used by the system developed. Serial port, USB and Ethernet communication interfaces are still the most popular among firms that develop embedded system, both in Croatian and other SEE countries' firms. However, firms from other SEE countries use Wireless more compared to Croatian firms.

Target processors for the system developed. There are some differences among Croatian and other SEE countries' firms according to target processors (Intel x86, Power PC, and ARM) for the system developed. Other ARM processors targeted for the system developed were IBM z series, CorTax, Philips PNX 1000 (Croatian firm), LPC1768 -Cortex M3(Croatian firm), Texas Instruments ARM, DSP and MSP430 chips, (SPARC) LEON, ARM9, S3C2440, ARM7, ARM9, Cortex A8, Cortex M0, M3, ARM7, and ARM9.

Process for best matching Hardware/Software co-simulation. Most of the SMEs software firms do not use process for best matching Hardware/Software co-simulation, while smaller number of firms from both Croatian and other countries' firms develop system on a hardware virtual platform, or design both software and hardware concurrently. Other process for best matching Hardware/Software co-

simulation were Effectiveness analysis defined by ISO 9001:2008, Matlab plotting graphs, Response time, load performance, mem performance, storage performance, Internal, Custom specific, and Built-in performance profiler in Visual Studio.

Performance requirements for hardware. In the process of embedded system development and usage it is important to define and attain performance requirements for hardware. The most targeted performance requirements are related to real-time, which is implemented by 86% of Croatian firms and 85% of other SEE countries' firms. Power-consumption is required by approximately two-fifts of both Croatian and total sample firms, while memory used is more used by total sample firms. Other performance requirements for hardware were overnight processing of large data quantities (Croatian firm) and radiation hardened.

Table 5
Software/hardware integration practices used by the sample firms

SW/HW integration practices used	Total sample (N = 29)	Croatian sample (N = 9)	Total sample, %	Croatian sample, %	Chi-square	P-value
Communication interfaces used by the software developed						
Serial port	19	7	66	78	3.571	0.059**
USB	19	7	66	78	3.571	0.059**
Ethernet	20	5	69	56	3.605	0.058**
Wireless (802.11)	17	4	59	44	4.504	0.034**
Other	2	0	7	0	7.254	0.007**
Target processors for the software developed						
Intel x86	22	5	76	56	8.913	0.003***
Power PC	4	3	14	33	10.040	0.002***
ARM (specify which)	10	4	34	44	2.102	0.147
Process for best matching Hardware/Software co-simulation						
Nothing (we do not know/use HW/SW co-simulation)	16	5	55	56	0.020	0.887
Developing SW on a HW virtual platform	7	1	24	11	5.853	0.016**
Designing both SW & HW concurrently	6	1	21	11	3.720	0.054**
Other	1	0	3	0	3.046	0.080*
Performance requirements for hardware						
Real-time	25	8	86	89	0.411	0.521**
Power-consumption	12	4	41	44	0.184	0.668
Memory used	16	4	62	44	6.503	0.011**
Other	2	1	7	11	0.977	0.323

Source: Authors' survey
Note: *** statistically significant at 1% level, ** statistically significant at 5% level, * statistically significant at 10% level

Other ARM processors targeted for the software developed were IBM z series, CorTax, Philips PNX 1000 *(Croatian company)*, LPC1768 -Cortex M3(Croatian company), Texas Instruments ARM, DSP and MSP430 chips, (SPARC) LEON, ARM9, S3C2440, ARM7, ARM9, Cortex A8, Cortex M0, M3, ARM7, and ARM9. Other process for best matching Hardware/Software co-simulation were Effectiveness analysis

defined by ISO 9001:2008, Matlab plotting graphs, Response time, load performance, mem performance, storage performance, Internal, Custom specific, and Builtin performance profiler in Visual Studio. Other performance requirements for hardware were overnight processing of large data quantities *(Croatian company)* and radiation hardened.

Performance evaluation and performance optimization for embedded system development

Performance evaluation methods should increase trust in embedded system solutions (Table 6). Performance evaluation methods used were Effectiveness analysis defined by ISO 9001:2008, Matlab plotting graphs, Response time, load performance, mem performance, storage performance, Custom specific, and Built-in performance profiler in Visual Studio. Listed methods are more used among other SEE countries' firms compared to Croatian firms, and Chi-square test has revealed that the difference is statistically significant at 5% level ($\chi 2$=8.335, p-value=0.015). Performance optimization for embedded system development is significant factor in attaining effectiveness and efficiency of embedded systems. Performance optimization for developed software and hardware used were gMeter, PMD, FindBugs, Check Style, Custom tools and methodology, manual, Device specific, and Built-in. Again, chi-square test has revealed that the difference is not statistically significant ($\chi 2$=0.022, p-value=0.882) between Croatian and other SEE countries' firms.

Table 6
Performance evaluation and performance optimization

Performance	Total sample (N = 29)	Croatian sample (N = 9)	Total sample, %	Croatian sample, %	Chi-square	P-value
Performance evaluation methods used						
No	21	7	72	78	8.335	0.015**
Yes	7	1	24	11		
No answer	1	1	4	11		
Performance optimization for developed software and hardware						
No	19	6	66	67	0.022	0.882
Yes	9	3	34	33		

Source: Authors' survey
Note: ** statistically significant at 5% level

Conclusions

In this paper the activities involved in embedded systems development issues, software/hardware integration practices and performance evaluation and optimization has been examined based on the survey sample of 29 SME software firms from selected SEE countries. Following are main conclusions from this research. Development of embedded systems incorporates number of important issues and they involve both technical and business aspects in terms of quality. However, there is still a lot of space for improvement, especially for SME software firms.

Diverse areas of applications (avionics, automotive, telecommunication, defence and control) for embedded systems developed indicate both flexibility of SMEs and increase of the embedded systems market, since number of emerging areas of application has been named (technical automation, finance, banking, medical care, camera motion control, space, video monitoring, and video surveillance).

The twenty nine SME software firms come into sight to specify that few SME firms did not yet implemented formal procedures for development of embedded systems like. Small number of firm use modelling languages (UML, Simulink/Stateflow), in most of the cases software has been tested manually and the source code has been rarely developed by usage of automatic tools. Coding standards/recommendations are rarely used, as well as verification of designed models. In addition, SMEs are using limited set of programming languages. In terms of software/hardware integration, firms have developed more various practices.

Firms are using all of the most currently popular communication interfaces at least to some extent, and variety of targeted processors are used for software developed. However, firms rarely use process for best matching Hardware/Software co-simulation. Still, much attention has been given to performance requirements for hardware, like real-time, power-consumption and memory used.

Although most of the firms from selected SEE countries are not implementing best practice in embedded systems development, Croatian firms lag behind especially in terms of: (1) lack of automated testing of the embedded systems, (2) usage of automatic source generators, (3) usage of coding standards/recommendations, (4) verification of the designed models, (5) process for best matching Hardware/Software co-simulation, and (6) performance evaluation and optimization.

MODUS project developed processes and software tools that allow the identification of design optimisations to be automatically applied, and the generation of source code that respects coding standards/conventions. In addition, these tools were tested as possible bridges against current shortcomings in the area of embedded systems development. In future work, data for segments of embedded systems applications which have not develop significantly, e.g. robotics as part of automatics, should be collected in order to make possible mutual ranking based on the maturity status of diverse embedded systems and corresponding technologies.

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