IDEAPUZZLE
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Use of heterogeneous platforms in space applications

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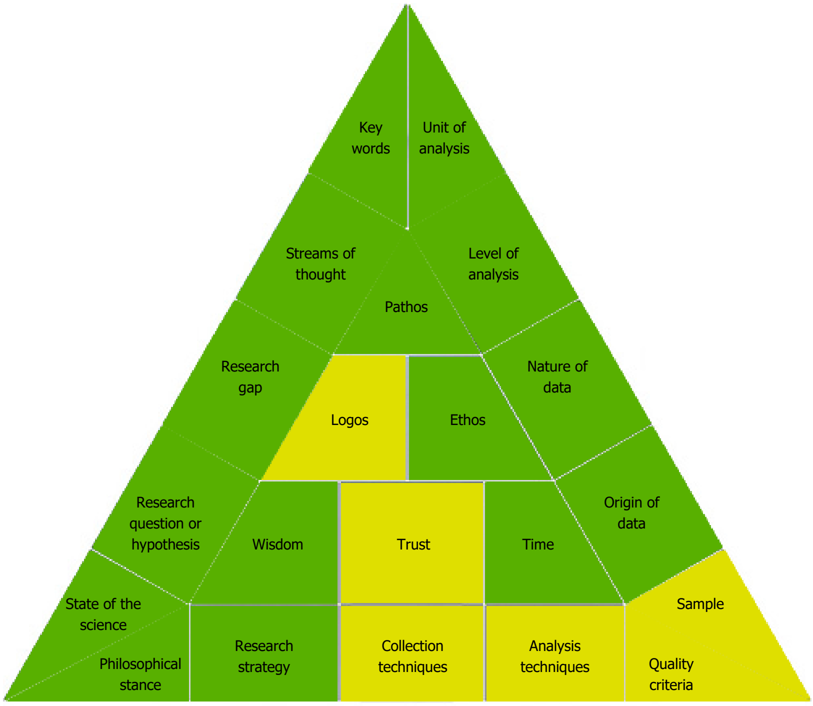
Self-evaluation: 86%



Key words

1/21. Theoretical question: what are the two main key words of your research?

My research focuses on the relationship between "heterogeneous platforms" and "space applications".
The title of my research design is "Use of heterogeneous platforms in space applications".
Space technology currently demands the use of commercial technology that reduces costs and can also take advantage of the growing boom that exists in new heterogeneous platforms. Space technology requires performance and robustness, as well as that the applications to be run have minimal energy consumption in terms of power generation and heat dissipation.
Heterogeneous computing involves experimentation with a large number of computing resources of different nature, in particular, multicore processors, graphics cards (GPUs), and FPGAs, among others. This diversity of resources allows to speed up performance and replicate calculations, that is, to increase the robustness of the application against uncontrolled faults.

Self-evaluation: 100%

Streams of thought

2/21. Theoretical question: what are the two main streams of thought of your literature review?

The use of commercial components for space applications is increasingly recognized by engineers and scientists. There is almost a full convergence of ideas in that the use of these devices greatly improves the capabilities of the applications [1, 2]. However, the streams of thought in the research line of this work are mainly divided into aspects related to fault tolerance.
There is a variety of solutions that have been developed to improve the efficiency of fault tolerance mechanisms. Fault tolerance techniques can be classified into hardware, software, or hybrid techniques, and researchers focus on one or the other depending on the characteristics of their system. There are certain differences between each of them, and relevant aspects that characterize them and influence the decision to apply one or the other, taking into account the advantages and disadvantages that they bring. Software techniques have certain advantages compared to other solutions, since a software modification is easier to perform considering that specific knowledge of architecture is not necessary, and is

sometimes the only solution, since the incorporation of additional hardware is impossible, or increases the costs of the system in general. In this area are [1-7]. The most effective tend to be hardware techniques, but they have the difficulty that it is necessary to modify the hardware, which is not always convenient or possible, even when it comes to non-intrusive techniques that only add hardware. Good results have been obtained in these techniques [8-10]. The combination of both techniques has been discussed by [11-16].

[1] Esposito, Stefano, et al. "COTS-based high-performance computing for space applications", IEEE Transactions on Nuclear Science 62.6 (2015): 2687-2694.
[2] Fuchs, Christian M., et al. "A Fault-Tolerant MPSoC For CubeSats" 2019 IEEE International Symposium on Defect and Fault Tolerance in VLSI and Nanotechnology Systems (DFT). IEEE, 2019.
[3] L. Mcfearin and V.S.S. Nair, "Control-Flow Checking Using Assertions", Proc. IFIP Intel Working Conf. Dependable Computing for Critical Applications, Sept. 1995.
[4] V.S.S. Nair, H. Kim, N. Krishnamurthy, and J.A. Abraham, "Design and Evaluation of Automated High-Level Checks for Signal Processing Applications", Proc. SPIE Advanced Algorithms and Architectures for Signal Processing Conf., Aug. 1996.
[5] Z. Alkhalifa, V.S.S. Nair, N. Krishnamurthy, J.A. Abraham, "Design and Evaluation of System-Level Checks for On-Line Control Flow Error Detection", IEEE Transactions on Parallel and Distributed Systems, Vol.10, NO.6, June 1999.
[6] P. Cheynet, B. Nicolescu, R. Velazco, M. Rebaudengo, M. Sonza Reorda, and M. Violante, "Experimentally evaluating an automatic approach for generating safety-critical software with respect to transient errors", IEEE Trans. Nucl. Sci., vol. 47, no. 6, pp. 2231-2236, Dec. 2000.
[7] B. Nicolescu, R. Velazco, "Detecting soft errors by a purely software approach: method, tools and experimental results", Design, Automation and Test in Europe Conference and Exhibition, 2003, pp. 57-62.
[8] T. Michel, R. Leveugle, G. Saucier, "A New Approach to Control Flow Checking Without Program Modification", Proc. 21th Int. Symposium on Fault-Tolerant Computing (FTCS-21), pp. 334-341, 1991.
[9] S. Bergaoui, R. Leveugle, "ISDM: An Improved Control Flow Checking Approach with Disjoint Signature Monitoring", Proc. 24th Conference on Design of circuits and Integrated Systems (DCIS), 2009.
[10] A. Benso, S. Di Carlo, G. Di Natale, P. Prinetto, "A Watchdog Processor to Detect Data and Control Flow Errors", 9th IEEE International On-Line Testing symposium, Kos, Greece, July 7- 9, 2003, pp. 144-148.
[11] M. Portela-Garcia,M.Grosso, M. Gallardo-Campos,M. Sonza Reorda, L. Entrena, M. Garcia-Valderas, and C. Lopez-Ongil, "On the use of embedded debug features for permanente and transient fault resilience in microprocessors", Microprocessors Microsyst. , vol. 36, no. 5, pp. 334-343, Jul. 2012.
[12] J. Rodrigo, A. Lapolli, L. Rosa and F. Lima "Detecting SEEs in Microprocessors Through a Non-Intrusive Hybrid Technique", IEEE Transaction on nuclear science, vol. 58, No. 3, June 2011.
[13] J. Rodrigo, M. Altieri, J. Becker and F. Lima "HETA: Hybrid Error Detection Technique Using Assertions" IEEE Transaction on nuclear science, vol. 60, No. 4, August 2013.
[14] A. Lindoso, L. Entrena, M. García-Valderas and L. Parra "A Hybrid Fault-Tolerant LEON3 Soft Core Processor Implemented in Low-End SRAM FPGA", IEEE Transactions on Nuclear Science, vol. 64, Issue 1, 2017.
[15] A. Martínez-Álvarez, F. Restrepo-Calle, S. Cuenca-Asensi, L.M. Reyneri, A. Lindoso and L. Entrena "A Hardware-Software Approach for On-Line Soft Error Mitigation in Interrupt-Driven Applications", IEEE Transactions on Dependable and Secure Computing, vol. 13, Issue 4, 2016.
[16] M. Peña-Fernandez, A. Lindoso, L. Entrena and M. Garcia-Valderas "Error Detection and Mitigation of Data-Intensive Microprocessor Applications using SIMD and Trace Monitoring", IEEE Transactions on Nuclear Science, 2020.

Self-evaluation: 100%

Research gap

3/21. Theoretical question: what is the main gap that your research addresses?

"The on-board computer (OBC) and related electronics, which constitute a large part of such spacecraft, have been shown responsible for a significant share of post-deployment failure" [17].
"Commercial-off-the-shelf (COTS) devices is often advocated as the only answer to the growing demand for more on-board computing power in future space missions" [18].
This research will focus on a gap related to the rapid growth of computational requirements in space applications, which can be assumed by heterogeneous platforms, but with the use of fault tolerance techniques that allow greater reliability in radiation environments.

[17] Fuchs, Christian M., et al. "A Fault-Tolerant MPSoC For CubeSats." 2019 IEEE International Symposium on Defect and Fault Tolerance in VLSI and Nanotechnology Systems (DFT). IEEE, 2019.
[18] Esposito, Stefano, et al. "COTS-based high-performance computing for space applications." IEEE Transactions on Nuclear Science 62.6 (2015): 2687-2694.

Self-evaluation: 100%

Research question or hypothesis

4/21. Theoretical question: what is the main question or hypothesis of your research?

This research addresses the following broad research question:
How can COTS components fault tolerance be improved for use in space applications and leverage its better computational performance compared to devices currently used in radiation environments?

Self-evaluation: 100%

State of the science

5/21. Theoretical question: what is the current answer to your research question or hypothesis?

Computational capacity of Multiprocessor systems-on-chip (MPSoC) devices is greater than that manufactured devices for radiation environments

exclusively. For that reason, they are positioning as excellent candidates for space agencies. NASA estimates that radhard (radiation hardened) microprocessors have a technology gap of around 10 years compared to their terrestrial counterparts, and that's why NASA is testing commercial Xilinx Zynq SoC devices on the International Space Station (ISS) [19], as hardware of this type could face the increasing demand for performance per watt in processors used in space [20, 21]. However, despite the high computational capacity of COTS, their use in space applications is limited by the effects of radiation. The solution is to use fault tolerance techniques to mitigate the effect of radiation [22, 23].
Different performance studies have already been carried out to assess whether different types of processing elements such as those included in Ultrascale+ MPSoC can be adapted to the growing needs in the space field. In [24], various devices for vision-based navigation are evaluated, including CPU, GPU, DSP, and FPGA in terms of several parameters that characterize the useful of these devices. The performance comparison between conventional CPUs and embedded ARM processors built into SoC devices is done in [25], where a relationship is shown involving CPU frequencies, performance and CPU types. On the other hand, [26, 27] establish that the FPGA can be used as a hardware accelerator for intensive computational requirements, so that the SoCs made up of FPGA and ARM processors continue to gain ground.
Previous research studies platforms with one or two types of processing elements, but does not explore the possibilities offered by an MPSoC, as a heterogeneous device that combines many types of processing elements. This work is focused on this line of research.

[19] NASA, "HyspIRI Final Report,"September 2018.
[20] European Space Agency, "Next Generation Space Digital Signal Processor (NGDSP) benchmarks from ESA", 2009.
[21] ___, "General Benchmarking and Specific Algorithms: NIR HAWAII-2RG BM", 2012.
[22] M. Berg, "NEPP Update of Independent Single Event Upset Field Programmable Gate Array Testing", NASA NEPP EEE Parts for Small Missions Workshop, 2014.
[23] NASA, Mission Design Division Ames Research Center, "Small spacecraft technology state of the art", NASA/TP-2015-216648/REV1, 2015.
[24] G. Lentaris, K. Maragos, I. Stratakos et al., "High-performance embedded computing in space: Evaluation of platforms for vision-based navigation", Journal of Aerospace Information Systems, vol. 15, no. 4, pp. 178-192, 02 2018.
[25] G. Mitra, B. Johnston, A. Rendell et al., "Use of SIMD Vector Operations to Accelerate Application Code Performance on Low-Powered ARM and Intel Platforms", in IEEE 27th International Parallel and Distributed Processing Symposium Workshops PhD Forum (IPDPSW), May 2013, pp. 1107-1116.
[26] D. Rudolph, C. Wilson, J. Stewart et al., "CSP: A Multifaceted Hybrid Architecture for Space Computing", in Proceedings of the 28th Annual AIAA/USU Conference on Small Satellites, 2014.
[27] X. Iturbe, D. Keymeulen, E. Ozer et al., "An integrated SoC for science data processing in next-generation space flight instruments avionics", in 2015 IFIP/IEEE International Conference on Very Large Scale Integration (VLSI-SoC), Oct 2015, pp. 134-141.

Self-evaluation: 100%

Philosophical stance

6/21. Methodological question: what is the philosophical stance of your research?

The philosophical stance of the research is framed in quantitative objectivism. It focuses on developing conclusions from facts, and not so much from meanings.

Self-evaluation: 100%

Research strategy

7/21. Methodological question: what is the qualitative, quantitative, or mixed-method of your research?

The research strategies of my project are based on a quantitative research study. Quantitative research involves studies that concern the collection of quantitative data directly or cases in which qualitative data is quantified to allow, for example, statistical analysis [28, 29].
The two research strategies adopted are simulation and lab-experiments. Through standardized tests (experiments and simulations developed) data are collected that characterize the behaviour of the system and allow its performance to be evaluated.
Experiments can be laboratory experiment or field experiment [30]. Laboratory experiments are conducted in controlled environments whereas field experiments are conducted in a real-world setting. This research is focused on laboratory experiments. Also, simulations are used. The simulation model reproduces the actual operations of the real components of the system with varying degrees of accuracy [30].

[28] Pinsonneault, Alain, and Kenneth Kraemer. "Survey research methodology in management information systems: an assessment." Journal of management information systems 10.2 (1993): 75-105.
[29] Klein, Heinz K., and Michael D. Myers. "A set of principles for conducting and evaluating interpretive field studies in information systems." MIS quarterly (1999): 67-93.
[30] Wohlin, Claes, and Aybüke Aurum. "Towards a decision-making structure for selecting a research design in empirical software engineering."

Self-evaluation: 100%

Collection techniques

8/21. Methodological question: what are the data collection techniques of your research?

There are certain research areas where interviews and questionnaires, which according to [31] can be considered the most direct instruments, typically present an incomplete picture. For that reason, in [31] a first attempt is made to provide a taxonomy of data collection techniques to carry out field studies in the engineering area, and this research uses precisely some of the data collection techniques mentioned in [31]. The proper data collection techniques for my research are: Analysis of Electronic Databases of Work Performed, Analysis of Tool Logs, and Static and Dynamic Analysis of a System. The first allows to analyse previous records of other investigations that serve as reference, whereas the second allows to analyse the logs of the tools used during the investigation for the programming and use of the platforms, as well as logs that the researcher implements and generates, such as my case. On the other hand, the third technique allows to analyse the code (static analysis) or the traces generated when executing the code (dynamic analysis) and to compare the values of various metrics.

[31] Lethbridge, Timothy C., Susan Elliott Sim, and Janice Singer. "Studying software engineers: Data collection techniques for software field studies." Empirical software engineering 10.3 (2005): 311-341.

Self-evaluation: 50%

Analysis techniques

9/21. Methodological question: what are the data analysis techniques of your research?

The data analysis techniques adopted in this research are quasi-statistics and multivariate statistical analysis. For the treatment of the results of the radiation experiments and the faults injections, mathematical tools are used (Matlab has been used) due to the high volume of data generated.

Self-evaluation: 50%

Quality criteria

10/21. Methodological question: what are the tactics of your research to ensure scientific quality criteria?

The quality criteria of this research are objectivist, given that it focuses on facts. Tactics are adopted to increase internal validity (quasi-inductive reasoning for theory development), and reliability (same benchmarks for all platforms, standardized radiation experiments).

Self-evaluation: 50%

Unit of analysis

11/21. Empirical question: what is the unit of analysis of your research?

In order to evaluate the effectiveness of heterogeneous platforms in space applications, the units of analysis under study are the heterogeneous platforms themselves. In this research, the same benchmarks are used on the proposed platforms, and are evaluated under similar conditions of radiation or injected faults.

Self-evaluation: 100%

Level of analysis

12/21. Empirical question: what is the level of analysis of your research?

The analysis is carried out at the platform level, that is, the system made up of various computational resources of various types. In principle, each computational resource will be analysed separately (multicore processors, GPU, FPGA, etc.), but the final objective is the analysis of the platform as a whole. Each platform will be evaluated to find an efficient implementation in these heterogeneous systems with respect to maximum performance, minimum energy consumption and maximum robustness to face unexpected faults.

Self-evaluation: 100%

Nature of data

13/21. Empirical question: what is the nature of the data of your research?

In this research, quantitative data is collected, and given its importance with respect to any qualitative data that can be extracted, the research is quantitative. The quantitative data collected are figures that define the best or worst performance of the system, energy efficiency and fault tolerance: execution time, number of floating point operations per second, energy consumption, performance per watt, the amount of errors produced taking into account the number of injected faults, the number of satisfactory recoveries of the system when an error occurs due to the effects of radiation, among others.

Self-evaluation: 100%

Origin of data

14/21. Empirical question: what is the origin of the data of your research?

All the data to be processed is primary. Research data is obtained through experimental procedures and benchmarks. The design and implementation of computational cores such as convolution, FFTs, Wavelet Transform, matrix decompositions such as SVD, QR, LU, among others, on the analysed heterogeneous systems will allow the collection of first-hand data to analyse the performance and energy consumption. In addition, representative fault tolerance data is obtained with logic fault injectors and radiation experiments at particle accelerator centres.

Self-evaluation: 100%

Sample

15/21. Empirical question: what is the sample of your research?

The sample in this research is inferential. The tests and experiments will be carried out on heterogeneous low-consumption architectures, with different characteristics in terms of number of processors, type of processors, etc. Platforms can be composed, for example, of one or more single or multi-core central processing units (CPUs), graphics processing units (GPUs), digital signal processing (DSPs), field programmable gate arrays (FPGAs). The variety of platforms on the market is very wide, and we will focus on some that incorporate various processing elements and make them excellent candidates for high computing. The initial work covers the study of the following platforms: Xilinx Zynq UltraScale+ MPSoC, which is composed of four different processing elements (PE): a dual-core Cortex-R5, a quad-core ARM Cortex-A53, a GPU and a high-end FPGA; Exynos 9610, which is composed of an Octa-Core Cortex-A73 CPU and a Mali-G72 MP3 GPU; and the Tegra Xavier chip, which features eight control/management Carmel cores (Nvidia's own custom 64-bit ARM cores) and a derivative of their Volta GPU with a set of finer changes to address the machine learning market. These are the chosen platforms in principle, expanding to others in the research process.

Self-evaluation: 50%

Pathos

16/21. Rhetorical question: what are the positive and negative emotions of your research?

The positive emotions of this research include the possibility of lowering costs in space missions, the availability of the use of satellites to larger and more varied sectors for research, scientific and technological developments, for example. It would be possible to access the space environment with less economic resources and with high-performance platforms.
Negative emotions include, for example, a possible development of militarization, espionage, and decreased privacy. Developing cheaper satellites accessible by more sectors would also increase space debris and constitute a risk factor for more relevant space missions and satellites.

Self-evaluation: 100%

Logos

17/21. Rhetorical question: what is the scientific logic of your research?

This study uses hypothetic-deductive logic, since it is based on general principles to reach a specific conclusion. The parallelization of tasks in other environments can be reduced to our specific case, as well as the principles that generate faults in electronic systems in general in radiation environments, can be applied to our study, starting from laws or general theories towards particular cases.

Self-evaluation: 50%

Ethos

18/21. Rhetorical question: what are the limitations of your research?

The theoretical limitation of this research is mainly given by bibliographic review capacity. To understand the behaviour of electronic systems in space applications, it is necessary to study the theoretical foundations of radiation and its impact on these systems. But at the same time, it is necessary to acquire great knowledge about the parallelization of tasks and their efficient use in this type of applications. Therefore, it is very difficult to cover all the theory presented in the literature.
The research strategy is limited to the impossibility of performing the analysis in real environments (space) with respect to fault tolerance, due to its high cost, and it is basically reduced to simulation, emulation and radiation experiments.
For the analysis of the research results, only a certain representative set of benchmarks and some heterogeneous platforms of all the existing ones will be taken into account, therefore the collection of data is limited by these factors.

Self-evaluation: 100%

Wisdom

19/21. Authorial question: what is your education and experience related to your research?

I hold a Telecommunications and Electronics Engineering, and a Master in Electronic Systems Engineering. Precisely, my master's thesis is developed in the field of the use and fault tolerance of commercial microprocessors in space applications and has been the starting point of my career and of acquiring knowledge in this field, which I will now apply to a wider sector. In the master's thesis, the implementation of a hardening software technique for multicore ARM microprocessors is presented, which will serve as the basis for the research work of the doctorate. Telecommunications Engineering, as well as my professional experience in this area have endowed me with diverse knowledge in the fields related to technology, but at the same time the Master's Degree has allowed me to specialize in a more specific line that is closely related to the purpose of the research that I am currently developing. Having belonged from the beginning of the master's study to the UC3M-SENER AEROESPACIAL chair, has increased my knowledge on the use of heterogeneous platforms in space applications. I think that all this education and experience position me at an excellent level to successfully meet the goals of this research.

Self-evaluation: 100%

Trust

20/21. Authorial question: who are the partners of your research?

During this research I will have the support of all the staff of the Electronic Technology department, mainly members of the Microelectronic Design and Applications (DMA) research group; it will be them, and fundamentally my thesis supervisors, who support my review of the literature, as well as the research strategy. The training capacity of this group is guaranteed by its scientific productivity, collaboration with

national and international reference groups and the participation of all its members in the Carlos III University Postgraduate Programs. Many of them have been my teachers in the Master, and with whom the study has been very helpful. I have two professors with experience in the two areas covered by my research as thesis supervisors: fault tolerance of commercial devices in space environments, and the evaluation and programming of high-performance platforms; my thesis is precisely the fusion of these areas of knowledge. One of my supervisors currently has been my supervisor during my master's studies.
Regarding data collection, this will be supported in a first stage by the injection faults experiments, and in a second stage, by radiation campaigns in specific facilities that will validate the experimental results of the first one.

Self-evaluation: 50%

Time

21/21. Authorial question: what is your availability of time and resources for your research?

This research is carried out within the UC3M Doctorate Program in Electrical Engineering, Electronics and Automation, with annual evaluation of the progress of PhD students. The program is full time; therefore, I have full availability. In addition, I am awarded a contract for Predoctoral Research Staff in Training, 91.89% financed with the European Social Fund, through the Youth Employment Operational Program and the Youth Employment Initiative (YEI) for such research. There are also several collaboration agreements with companies in the aerospace sector, as well as a project financed by the Community of Madrid, Madrid FlightOnChip, and two projects from the National plan (one recently awarded in June 2020). The contracted researcher is part of the work team that is in charge of the research tasks related to this collaboration. During the contract period, weekly meetings will be held where the contracted researcher will participate together with researchers from the DMA group, and periodically some of the companies involved will participate in these meetings.
For the development of the proposed thesis, the researcher will need high-performance computer equipment made up of heterogeneous systems, and for this, access to equipment belonging to the HPC&A group of Universidad Jaime I of Castellon, and to the Spanish Supercomputing Network will be available.
Additionally, in the course of the investigations it will be necessary to carry out radiation campaigns (beam time in the corresponding installation) and use additional devices to those used for development, to expose them to radiation. The experiments will be carried out in European facilities that regularly collaborate with the DMA research group, the target centre being the National Accelerator Centre located in Seville, with which the DMA group has collaborated continuously and has carried out numerous radiation campaigns of latest generation microprocessors and other circuits for space applications.
Regarding project management skills, I consider that I am creative, I manage time very well, I am very organized, and I have the ability to prioritize tasks according to their importance. I also consider that I have critical thinking, and I am able to critically self-evaluate the development of my activities. Furthermore, my progress is constantly monitored during the course by my thesis supervisors, and annually by the Academic Committee of the Doctoral Program. The use of various project management software will allow me to strictly comply with the planning of tasks proposed in the initial research plan that has been developed and approved.

Self-evaluation: 100%