Embedded multi-core systems for mixed criticality applications in dynamic and changeable real-time environments

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05A	Danfoss	Juha Kuusela	Edited all chapters based on contributions by different WP10 partners.

Document History

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v0.2	16/3/2017	Javi Cano	Updates to machine vision part
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Publishable Executive Summary

Living laboratory applying EMC2 technologies for industrial applications and logistics has been a success. Danfoss, NXP Semiconductors GmbH, Ambar and ITI all have plans to commercialize the results. We can expect to see market impact as increased flexibility and improved security. Results will also have an ecosystem impact.

We set out to achieve seven different objectives. Successful combination of hard real-time and soft real-time functions was demonstrated several times. FPGA together with multicores was used and even model based design with delayed decision of what functionality to place to the FPGA was demonstrated. Several algorithms were designed for multicores.

Security as service was supported by developing a hybrid solution (MSECROT) to provide flexible root of trust that can be easily integrated to existing networks. Integration was demonstrated by showing how multiple tracking technologies can be used together and secured by MSECROT. Attempt to develop a solution that would allow us to offer safety as a service was not as successful. It is difficult to convince certification authorities that flexible and programmable safety solutions are reliable.

Finally, we managed to utilize multicore processors and parallel algorithms to implement efficient and scalable solution to manufacturing quality control using machine vision.

We used predefined KPIs measuring the progress against previous solutions. All KPIs are not easily quantifiable but the progress is significant in all area. In those areas where we could measure it the improvement compared to our current products is many folded.

Industrial applications and logistics turned out to be a fruitful domain from innovation perspective. We found new solutions for combining hard and soft real-time, we learned how to cut down the component on PCB layouts, several new algorithms turned out to be usable, generic secure element API specification was achieved and multi core root of trust demonstrated. Correctness of automatic estimation of performance improvement caused by paralleling was confirmed.

We wish to thank the funding agencies and our partners for giving us this opportunity to grow together.

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1. Introduction

1.1 Objective and scope of the document

This document describes how well WP10 achieved the goals outlined in the technical annex [1]. The document is intended to anyone interested in learning what was achieved in EMC² project from the perspective of the industrial manufacturing and logistics.

1.2 Structure of the deliverable report

This document follows the structure of EMC² technical annex [FPP_EMC2_AIPP5]. It opens by giving a look into commercialization of the results. Then the market impact of the results in some dimensions is estimated. We set our self a number of functional objectives and their fulfillment is outlined. EMC² has a number of key progress indicators for each living lab. The progress regarding the KPIs for WP10 is estimated based on the final prototypes and measured comparing the prototypes to current products. Finally, fulfillment of innovation potential is highlighted.

2. Commercialization of the results

The results achieved in this work package have commercialization potential.

Based on the results and the design of Drives architecture in task 1, Danfoss has decided to include EMC2 technologies into future products. Expected turnover of those new products is over 1000 MEUR after year 2025.

NXP Semiconductors GmbH has developed Multi Secure Element Core Root of Trust (MSECROT) modules in task 2. These modules have potential to be used as IoT Gateway Trust Anchor for cloud solutions. It is currently planned to be used as reference design and Technology Demonstrator product for customers. Expected turnover is pending future estimation.

Ambar will develop specific products (nodes and gateway) to offer the technology demonstrated in task 3 to customers interested in tracking solutions both for indoor and outdoor use. Ambar plans use the learnings to improve its products used for “Ambar Salud” environments (Pacient TV*, Unfi-ed Communications, Connectivity, Communication Networks, Management and Security Systems, etc.). Expected turnover has not yet been estimated.

ITI will integrate the improvements achieved within the EMC2 framework developed in task 4 to reduce latency and to increase productivity in the ZG3D inspection system [Observatorio]. Expected turnover has not been estimated. Nevertheless, the good results of the work in this project are considered key points for its future industrialization and implementation into manufacturing production lines.

2.1 The market impact on industrial manufacturing and logistics

2.1.1 Increased flexibility

Multicore control architecture brings performance and scalability. For example, the control design for the new drives product line is expected to support drives for wide range of application ranging from HVAC to motion control and from low power to medium voltage.

Combination of multicore control and multiple wireless communication channels makes it possible to exploit different indoor and outdoor location technologies. The use of different location technologies will allow the fast integration of the best technologies in different environments for customized location tracking solutions.

The share performance and separation of concerns offered by multicore platform enables programmability. For drives we can offer protected application programming environment to machine builders and end-customers. This helps machine builders to reach higher productivity and offers more flexibility for factory automation. Savings in automation will drive prices down and is expected to increase the usage of drives leading to increased energy efficiency.

2.1.2 Improved security

Tamper resistant parts in SoC can be used as the root of trust. FPGA can be used to run the algorithms at start-up phase and chip internal RAM can be used to store the secrets. For drives this enables connection to IoT networks.

With EMC2 technologies it is possible to provide security as service to any network. The solution is scalable, interoperable, configurable and modular. The MSECROT module can be used as Security

Gateway (Secure communication and authentication) that provides certified, tamper resistant, isolated secure processing environment and secure storage options.

2.1.3 Ecosystem impact

EMC2 technologies support both access and security. This has big potential ecosystem impact. For example, programmable drives connected to factory automation system for control and to Industry IoT for analytics can provide a platform for European ICT industry to build services that can be offered worldwide.

3. Achievement of functional objectives

Several functional objectives were set for WP10. Most of the time we managed to exceed our original expectations. Only one objective was missed.

Objective 59 - Industry: Combine hard real-time and soft real-time functions
We developed an architecture and several demonstrations showing that both soft real-time and hard-real time functions can be supported by the same system, guaranteeing the timing for the hard-real-time functions and improving the quality of service for the soft-real-time functions. Based on the measurements this objective was accomplished better than we expected.

Objective 60 - Industry: FPGA multicores
We implemented multicore solutions for mixed-criticality applications using combination of FPGA technology, soft cores and ARM cores [ICIT_2017]. We also demonstrated a set-up where functional deployment can be made on different resources on a multicore from a system model. Also with this objective we managed to achieve more than originally expected.

Objective 61 - Industry: Algorithmic design for multicores
The objective to design control algorithms, such as electrical drive control, to take advantage of the multi-core platform features was achieved. We were also able to demonstrated that the added performance of the multicore makes it possible to also implement algorithms like model based predictive control [IEEE_TIE_2016]. Due to highly nonlinear behavior of the frequency converter it has been too expensive computationally to implement on traditional embedded platforms. In addition to control algorithms, we also demonstrated various other algorithms running in the multicore environment, including real-time communication and image analysis.

Objective 62 - Industry: Safety as a service
This objective proved hard to achieve for frequency converters. Flexible and programmable solutions for functional safety are not popular among certification bodies. We are now planning to offer a service to implement new safety functions using the existing certified framework and support customers in the certification process. This cannot be considered as fully achieving the original objective.

Objective 63 - Industry: Security as a service
This objective has been reached by the MSECROT prototype. It has a hybrid solution combining multiple secure elements and managing processors to provide flexible roots of trust. It has better latency, efficiency and bandwidth utilization compared to single secure core solution. Flexibility makes it possible to use this solution to provide security for existing networks. This was demonstrated in combination with the industrial tracking demonstrator.

Objective 64 - Industry: Tracking on multicores

This objective has been achieved. Using multicores, we implemented and integrated multiple tracking technologies. These were integrated with data management systems, to support the manufacturing and logistics processes.

Objective 65 - Industry: Machine vision quality control

The objective was to exploit coarse-grained parallelism using multicores to implement manufacturing quality control using machine vision. We demonstrated that it is possible to enable algorithm parallelism for the 3D reconstruction software. OpenMP was applied to some functions of the software and an evaluation of the performance for intensive computation tasks on a variety of execution platforms was presented and compared. All this work allowed for a coarse exploit of intra-node parallelism and therefore it was useful to reduce system latency.

Furthermore, inter-node parallelism was achieved by fairly dispatching full captures (32 images + 3D calibration) to different "worker" nodes. Each worker node performs a 3D reconstruction and some 3D inspections saying if the analyzed object is correct or not. In this way, throughput of the inspection system raises.

4. Key progress indicators

The success of EMC2 in meeting the set goals is measured by a selected number of different progress indicators. The table below list the indicators selected for WP10. Achievement are described by different tasks and demonstrated in the public demonstrations.

We have also indicated progress in achieving decrease in cost of system design (KPI60). This KPI was not assigned to WP10. However, cost is such an important driver for progress in industry that it is worth considering also in this work package.

KPI	**Name**	**Achievement**		**Improvement**
48	Synchronization accuracy	Synchronization accuracy improvement compared to previous product line is significant. Maximum measured jitter in the current prototype is over 100 times below the jitter in existing product line.	T1	>100 times
49	Latency values	Predicted latency value from fieldbus trigger to motor is over 10 times below latency in current products.	T1	>10 times
49	Latency values	Parallel processing of security request reduces the response time significantly in comparison to single secure element (at least 2-3 times better)	T2	Significant
50	Determinism features	Architecture supports declaratively configurable rate monotonic scheduling with data based synchronization. It allows to maintain deterministic process control and at the same time supports best effort computations with available resources. This is significant improvement over previous product architecture.	T1	Significant
51	Power	Integrating most of the server/client code into the gateway as well as multiple communication interfaces and using low-power wireless nodes lower significantly the power requirements from previous implementations combining multiple third-party devices.	T3	Significant
52	Efficiency	MSECROT scales well with increased number of secure elements. With support to multiple security protocols and built in redundancy it enables flexible and scalable security solution that offers interoperability with different external networks.	T2	Significant

52	Efficiency	Having a multi-core solution that enables implementing higher level applications (web/server apps, databases) in one core (running an embedded operating system) and lower level hardware functions (interrupt handling from external HW) in the other core (running bare bone or with a very light task manager) allows to provide very efficient implementations for mixed critically applications in the same device.	T3	Significant
53	Use of bandwidth	Programmable frequency converters support a distributed machine control allowing actuators take care of local measurements and axis synchronization. Central synchronization has been the main consumer of bandwidth in multi-axis machines and available bandwidth has limited machine size. In this domain the decrease of bandwidth need is significant.	T1	Significant
54	Productivity	The improvement achieved exploiting parallelism, by reducing the latency (around 3 times, from 24.5 milliseconds to 7.9 milliseconds) and providing theoretically unbounded system scalability, will enable a higher improvement than 20% for the productivity key performance indicator of the manufacturing inspection system.	T4	Significant
60	Cost of system design	Increase performance combined with programmability and wider functionality make it possible to replace other components with drive. This lowers the cost of overall system design significantly.	T1	Significant
60	Cost of system design	By integrating multiple applications and communication services in only one gateway is possible to reduce costs previously allocated to multiple devices.	T3	Significant
60	Cost of system design	By using commercially off the shelf components, the cost and time to market is significantly reduced. Since most of the components in MSECROT are manufactured by NXP, the cost of sourcing products from other entities and eventually sharing profit is zero. Also usage of certified secure elements reduces the cost of re-certification of complete solution.	T2	Significant

5. Fulfilment of innovation potential

In the beginning of the project several areas were seen as having potential for innovations.

New ways of achieving safety critical requirements
State of the art in addressing safety critical requirements is based on multiplication of the physical hardware components. In task 1 we design an architecture were safety critical and not safety critical parts are mixed by using black channel to connect safe parts to normal control. Use of sensor-less algorithms as part of the safety solution decrease the need for sensors. This architecture has on conceptual level been approved by a certification authority. This can be considered to be partial success as some extra physical hardware is still needed to have a certifiable solution.

Combining hard real-time and soft real-time functions
State of the art solutions often have separate processors for hard real-time tasks (e.g. DSP or FPGA) and for soft real-time tasks (e.g. MCU). The innovation potential comes from mixing different time domains and thus achieving better resource utilization and more flexible performance [TECS_2015]. We have demonstrated that using multiple cores and separate co-existing schedulers to separate hard and soft real-time functions we can both serve the time critical computations and give good throughput for less critical computations. Using time synchronous communication to connect computing elements we have shown that entire system can be made to operate with low jitter improving the predictability to the system. This can be seen as success. The result is significantly improved performance without adding any costs.

Hardware layout
Existing products have custom PCB hardware layouts for different sets of safety, performance, and reliability requirements. With the new architecture, we have demonstrated a potential that single

multicore design with variable number of cores has in reducing the need for custom PCB layouts. The planned product line has significant reduction in the number of control module variants. This lowers the price, lowers the software variation, decreases the need to store spare parts and improves the logistics.

Algorithmic design for multicore
Algorithms for multicore processors are often adopted from their single core counterparts without investigating the possibilities of their improvement. Several different approaches were tried out:

- Model driven design in Simulink for heterogeneous SoC made it possible to select whether implementation will be in FPGA or in SW after the model has been made.
- Model driven predictive control algorithm could be implement so that it allows optimization of the magnetic flux, including flux weakening in a high-speed region. The design uses the benefits of the RT and FPGA combination to face the large memory demands of a linear explicit MPC implementation.
- An offline analysis tool suite known as “art2kitekt” was used to improve a 3D reconstruction algorithm. The tools allow the engineer to model and analyse evolving system prototypes in different ways, from “Best Computation Time” analysis in a hard real-time parallel task set to “Bus Bandwidth” analysis for the system architecture.

Flexible binding time of the safe functions
Safety critical products are typically created by binding the safety functions during the product development time to guarantee that the right safety solution is deployed. This is process is slow and the resulting solution is not very flexible. This is mostly a concern for frequency converters. They have safety functions and are used as a part of overall machine or factory safety. We are planning to offer a service to implement new safety functions using the existing framework and support customers in the certification process. Seen from customer perspective, this is expected to be faster and more flexible that the current solution.

Generic Secure element API specification
We have developed an interoperable and standardized host APIs for accessing secure element functionalities. The underlying SW layer handles translation of standard external API into secure element specific command response interface. This way secure elements can be replaced without altering external interfaces.

Multi Core Root of Trust Solution
Secure elements are traditionally done using single core solutions. MSECROT module developed in WP10 is composed of central Arbiter/Scheduler (NXP ARM Cortex M3 LPC18S37) that distributes security loads to multiple secure elements (NXP A7005 / A70CM). The module offers standard wired/wireless interface to external network and secure elements are internally connected to central handler via I2C interface. It provides certified, tamper resistant, isolated secure processing environment and secure storage options.

Off-line assessment of productivity scalability by means of modeling and analysis with a WP02 tool-suite
Automatic estimation outperforms the state of the art on manual estimation of potential improvements based on direct and simple linear regression estimates with the number of available cores. The improvement consists on the use of a previous model of the system execution platform (hardware) and task set (software) to perform a methodological and more precise estimation with the application of specific algorithms over the previously modeled multicore system.

6. Conclusions

Work package 10 has achieved most of the goals set for it. Results in model driven design and implementation are very satisfactory. We have reached the goals in terms of development speed and quality. New architectures also seem to perform as expected in fulfilling both the real-time requirements and the capacity requirements. Development in security area is solid and will improve the security of industrial systems significantly. Communication and tracking solutions for mixed radio and protocol environment have progressed according to the set requirements. Solution for 3D visual inspection for manufacturing quality has improved in productivity and can be scaled.

Safety is the only area were our original ambitions will not be satisfied. We were looking for a flexible safety solution were additional hardware investments would have been minimal and flexibility would have allowed us and even our customers to combine different certified safe components into new designs without the need for recertification. We have made some progress. Use of non-safe communication channels are accepted as long as they are monitored and use of pre-certified components will speed the certification process. However, we will still far away of providing “programmable safety solutions”.

Based on the prototypes WP10 is also on track in achieving the commercial goals set for the project. In some cases, the decision to develop new products based on the results has already been made.

7. References

[FPP_EMC2_AIPP5]: FFP document of Artemis AIPP5 EMC2 project

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