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## AI for New Devices And Technologies at the Edge

### D5.12 Report about the evaluation results of the use cases

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<b>Version</b>	1.0	<b>Status</b>	Final
<b>Description</b>	This document describes the final evaluation and benchmarking results of the implementations for all ANDANTE use cases, which show the applicability of the technologies and platforms developed by the project.		
<b>Work Package</b>	WP5 – Application Integration and Evaluation.		

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## Abstract (Published Summary)

This deliverable includes contributions of all WP5 tasks and is the final deliverable of WP5 of ANDANTE. It presents evaluation parts and processes as well as the outcome of the exploration and evaluation of all ANDANTE results in the context of more than 19 demonstrators over 14 use cases (UC) developed by the partners in the project. The specific focuses of the use cases and content of this deliverable are as follows:

- **UC 1.1 “Indoor Positioning, Recognition and People Counting”** is separated into three sub-demonstrators:
  - **Setup A** was implemented by IFAG and EESY based on platform 4.2 that includes the Multi-SNN-ASIC-Unit by IFAG and with it the partners explored and evaluated distributed SNN algorithms besides the platform itself. The results of this evaluation show that SNN ensembles have a comparable performance to single SNN models and CNNs regarding accuracy. However, they consume more energy and requires more memory compared to the reference implementations. Furthermore, IFAG and EESY present the evaluation of a stacking ensembles with different types of AI-algorithms showing the potential of combining different AI types into one approach, since this ensemble had the best accuracy of all approaches that were deployed on the platform.
  - **Setup B** was realized by TUD based on the SpiNNaker 2 and TUD used it to evaluate the algorithms for SpiNNaker they developed in ANDANTE. Specifically, they showed that the model developed for the use case has high-energy efficiency, requires less pre-processing and keeps a high spatial resolution compared to standard approaches like FFT-based approaches. Overall, the TUD benchmark results reveal that AI can help surpass limits of conventional radar signal processing.
  - **Setup C** was developed by HEI and FHG with ASIC 3.1b in mind. In this deliverable they present a version of YOLOv3-tiny model based on data gathered with a “Thermopile Infrared Array-based Camera” from HEI. To fulfil the requirements of the application FHG experimented with different pruning and quantization configurations that were applied to the model. Afterwards, the partners did an evaluation of the models with the different configurations, and it was determined that the model with 4 bit-quantization and 50% pruning level was the best performing one, since this model required for an inference the least number of multiply-accumulate operations and memory as well as had the best average precision.
- **UC 1.2 “Colour Classification at the Edge for Quality Control”** was implemented by IFAG to evaluate IFAGs analogue neural network ASIC, the ASIC 3.2 of ANDANTE. They show that this technology has the potential to realize tinyML or extreme edge application. However, the partners show that there is still a lot to do to efficiently implement these applications, since during the evaluation the ASIC 3.2 was not able to reach the target KPIs.
- **UC 2.1 “Autonomous Weeding System”** by B-INP and CEA is based on platform 4.1a and ASIC2.1 and was used to evaluate neuromorphic AI-based classification and accelerators for this use case context. The partners proved that the hardware developed by CEA in ANDANTE has the necessary performance in weeding systems or VineLaps. However, the partners point out that more KPIs need to be investigated, more real-world tests need to be performed and state-of-the-art comparison need to be

made to generate a full conclusion and go towards commercialization of the ANDANTE results.

- **UC 2.2 “Tomato Pest and Disease Forecast”** by INOV, CCTI, ITAL, T-PRO and CEA is based on platform 4.1a and ASIC 2.1. This use case was used to evaluate these neuromorphic technologies for this application. The partners show that the ANDANTE results provide a performance that make them viable for the applications, but they lack behind state-of-the-art approaches like YOLOv8 that currently perform better on average. The partners discuss the reasons for why that is and outline strategies to solve this gap.
- **UC 3.1 “Drones/USV”** was implemented by TRT and CEA based on platform 4.1a, ASIC and a TRT FPGA board to compare three different approaches for drone control. These approaches are a formal CNN on ASIC 2.1, a formal CNN on the TRT FPGA board and a hybrid-formal-spiking topology on the TRT FPGA board. The partners show and discuss the advantages and disadvantages of each approach. Specifically for the first two approaches, they determined that the best solution between the two approaches will depend on each specific situation, where a balance should be made between flexibility, power consumption and development/fabrication cost. However, for the last approach TRT theorized initially that a spiking neuron will consume less electrical power than a formal one as it does additions instead of multiplication-accumulations. This theory was proven wrong in the context of the use case setup.
- **UC 3.2 “Underwater Acoustic Signal Classification”** by ALSE, CEA and SynSense was realized based on platform 4.1a, ASIC 2.1, platform 4.1b and ASIC 1.3 to evaluate SNN and CNN algorithms in this use case context. The results of the evaluation show that both technologies provide very good performance for this application. However, improvements are needed to achieve commercially effective underwater drones in the future. For instance, the SNN hardware would require a specialized frontend to leverage its full potential in this context. Besides this the partners discuss and present other improvements.
- **UC 3.3 “3D Object Detection and Classification”** of Road Users based on LiDAR and Camera” implemented by VIC and CEA is based on platform 4.1a and ASIC 2.1 to evaluate CNN based approaches for this application. The results of the first evaluation showed that the configuration with ANDANTE components provides lower accuracy performance than the state-of-the art, but the power consumption should be much better. Unfortunately, the availability of the 4.1 platform just at the end of the project did not allow a new evaluation to be carried out. However, the demonstration carried out during the final review and the performances obtained could give hope for very good performance improvements. The partners discussed the possibility of continuing the full evaluation of ASIC 2.1 and the 4.1a platform after the project end.
- **UC 3.4 “Robust Autonomous Landing”** is the use case of BR&T-E, TVES, GRADIANT, CARTO and CEA under the lead of BR&T. This use case is based on the Xilinx ZCU102 and Kria KV260 boards to evaluate the potential of neuromorphic technologies for this application. The partners discuss the relevant and extensive insights gained from the evaluation regarding the performance characterization of diverse DNN models when running inference on different types of energy-efficient hardware that are on board of a flight demonstrator. Based on these insights and evaluation results the potential of the ANDANTE results for the different tasks for the autonomy of aerial vehicles was proven. This means that all the targets for the KPIs defined at the beginning of the project were fulfilled.

- **UC 3.5 “Path Planning for Autonomous Steering”** is led by GML and based on GML hardware, GrAI VIP. It was realized to evaluate the use of the hardware and subsequent SoCs on e.g. warehouse robotics usages. With work at this use case, GML did to not only investigated, determined, and evaluated on how to train GrAI Core on an autonomous steering network, but also gained insights regarding what it takes to integrate such networks in real-time operations, including some aspects of vehicle telemetry (steering, etc). Overall, it was proven that the setup met the target KPIs partially. It is only partially, since the targets for accuracy, latency and degradation were not fulfilled. GML discusses these gaps in this deliverable.
- **UC 4.1 “Multi-modal Image Processing and Device Tracking in medical X-ray and Ultrasound Images”** was implemented by PMS and IMEC-NL to explore the capabilities of SNNs to perform complex medical image analysis tasks. Hence, the partners created a setup based on the IMEC-NL SENECA FPGA board and compared to a demonstrator implemented on NVIDIA GeForce GTX 1080Ti which serve as the target and reference, since it is currently used by PMS for the image processing and device tracking. Hence, the partners analysed and discussed the results in depth and outlined improvement strategies.
- **UC 4.2 “Ultra-sound Acquisition and Processing”** by PRE, IMEC-NL and GML was used by the partners to explore the capabilities of the neuromorphic technologies of IMEC-NL, the SENECA FPGA board, and GML, the GrAI VIP hardware, to perform medical analysis tasks. As reference and target they used an implementation based on the Nvidia Jetson Nano TX2. Overall, the evaluation against the reference showed that the neuromorphic platforms deliver on the promise of low power. However, the ANDANTE setups are worse regarding accuracy. The results are discussed more in depth by the partners in this deliverable.
- **UC 4.3 “Glucose Monitoring”** was implemented by IFAG and EESY with the SNN platform 4.2 of IFAG to explore and evaluate parallelized and distributed SNN algorithm for smaller applications. Additionally, the partners wanted to determine whether the implemented setup with SNNs would enable an efficient realization of glucose monitoring. Overall, the work in use case showed that SNNs are in general not the best fit for this application and the chosen sensor was not the right choice, since it delivers data that result in unstable classifications. Furthermore, on the algorithms side it seems that this problem is too small for ensembles. The partners discuss these issues and outline steps to solve them.
- **UC 5.1 “Consumer Auditory Processing”** is divided into 4 sub-use-cases:
  - **UC5.1a, UC5.1b and UC5.1c** are use cases in the audio processing domain that were worked on by SynSense and realized with the ASIC 1.3, platform 4.1b and the DYNAP-SE2 hardware development kit to develop, optimize, and evaluate the SynSense SNN algorithm and hardware concepts. The evaluation of these use cases showed that the hardware and algorithms fulfill all of the targets and in some cases, they drastically exceed the target.
  - UC 5.1d was implemented by FHG to optimize and evaluate platform 4.3 and ASIC 3.1 that were developed by FHG in ANDANTE. The evaluation of this sub-use-case proves the technical excellence of ANDANTE, since ASIC 3.1 and the deployed algorithm easily fulfill all the target KPIs. The ASIC even exceeds some of the indicators by a wide margin.
- **UC 5.2 “Vision-Based Human-Computer Interaction”** by CSEM is based on platform 4.4 from SynSense and is used to develop and evaluate approaches for CNN

to SNN conversions in the project. With this evaluation, CSEM showed the performance of the approaches they developed in ANDANTE and proved that overall, the SNNs on platform 4.4 outperform state-of-the-art algorithms deployed on STM32L4R9 and Coral Edge TPU. CSEM gained a lot of insight about SNNs during their work at UC5.2. This insight was used by them to outline next steps to further optimize the algorithms and hardware implementations.

Overall D5.12 shows the following results based on the evaluation:

- Considering that one of the main objectives of ANDANTE was energy efficiency, this was demonstrated through the different demonstrators developed which exceeded the reference demonstrators. For example, the gains in energy consumption are one or two orders of magnitude lower than those of the reference demonstrators.
- It has been shown that there is a trade-off between performance and flexibility. In certain use cases, such as medical applications where the requirements are very high, an ASIC should be considered as the ad hoc solution.
- For simple applications like the audio use cases of UC5.1, ANDANTE solutions outperform targets and state-of-the-art solutions in every aspect.
- More complex applications like UC1.1 can be realized with ANDANTE hardware and software. However, they do not outperform state-of-the-art in every KPI.
- The partner defined based on the evaluation results improvement and optimization strategies as well as further research topics and other next steps that need to be taken to bring the ANDANTE results to market or leverage them for further research.