CHIST-ERA Project Periodic Report

APROVIS3D Analog PROcessing of bioinspired VIsion Sensors for 3D reconstruction **Periodic report n° 4 (final project report)** **December 31, 2023**

This document must be filled in by the project coordinator with the help of the project partners and must be sent to anna.ardizzoni@anr.fr (ANR, CHIST-ERA Joint Secretariat) and to giorgio.carpino@miur.it (MIUR, CHIST-ERA Projects monitoring) at the end of each period (typically every year after project start). The Joint Secretariat ensures distribution to the concerned research funding organisations. The project coordinator is responsible for sending a copy of the report to the project partners.

The information provided should cover the whole duration since project start (information from a previous period should be kept in for the next period if still relevant; the report for the final period thus also constitutes the project final report covering the whole project duration).

1. Identification

Project Id	
CHIST-ERA Call topic	ACAI
Project acronym	APROVIS3D
Project title	Analog PROcessing of bioinspired VIsion Sensors for 3D reconstruction
Start date	01/04/2020
End date	31/12/2023 (45 months)
Website	http://www.aprovis3d.eu

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Please indicate if you carried out an extension request to one of the national funding organisations. If a research organisation has obtained an extension of the project, please indicate:

- *Which research organisation made the request;*
- *To which national funding organisation and;*
- *How many additional months were requested.*

The consortium will send in due time a 6-month extension request, due to the sanitary situation.

Note that in France, ANR-funded project started from April 2020 are given a systematic 6-month extension. The final date for French partners already includes this extension.

Greek partners (UNIWA and NTUA) have experienced a difficult extended delay for accessing the funding, which became available only at the end of March 2021. Greek partners did submit an extension request until 04/12/2023 to GSRI. Due to a consecutive slowdown in the realisation of the demonstrator, the whole consortium submitted to CHIST-ERA an extension request until 31/12/2023, that has been granted by CHIST-ERA and to all partners.

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2. Publishable Summary

(Indicative length: 2 pages)

The content of this section is intended for communication by CHIST-ERA on the project, mainly through its website. Style should be adapted to communication to a wide audience and quality must be suitable to enable direct publication. The authors authorize this publication by CHIST-ERA. The publishable summary should be updated for each periodic report. Authors can provide further updates at any time.

The publishable summary should provide the following information:

- *The project context and objectives;*
- *The methods and approaches used, the work performed since the beginning of the project, and the main results achieved so far;*
- *The expected final results and their potential impact and use (including the socio-economic impact and the wider societal implications of the project so far);*
- *The address of the project public website, if applicable.*

Further relevant information such as Illustrations (including diagrams or photographs, clear of any copyright issue), contact details or list of partners are encouraged.

APROVIS3D project targets analog computing for artificial intelligence in the form of Spiking Neural Networks (SNNs) on a digital architecture. The project investigates neuromorphic architectures applied to coastal surveillance using an aerial robot.

Computer vision systems widely rely on artificial intelligence and especially on neural network-based machine learning, which recently gained huge visibility in the form of deep convolutional neural networks. As of today, the training stage for these architectures is both time and energy consuming. In contrast, the human brain has the ability to perform visual tasks with unrivalled computational and energy efficiency. It is believed that one major factor of this efficiency is the fact that in biology, information is vastly represented by short pulses (spikes) at analog – not discrete – times.

However, computer vision algorithms using such representation still lack in practice, and its high potential is largely underexploited. Inspired from biology, the project addresses the scientific question of developing a low-power, end-to-end analog sensing and processing architecture of 3D visual scenes, without a central clock and it aims to validate them in real-life situations.

More specifically, the project develops new paradigms for biologically inspired vision, from sensing to processing, in order to help machines such as Unmanned Autonomous Vehicles (UAV), autonomous vehicles, or robots gain high-level understanding from visual scenes. Event-based neuromorphic vision sensors have led to an increased interest in studying and developing a new class of fast and accurate vision systems.

This project ambitions to develop a new design of event-based vision system, based on (1) improved event-based vision sensors, (2) new neuromorphic algorithms (3) their implementation on neuromorphic architectures. With this approach that diverges radically from the mainstream frame-based approaches, we expect a more efficient processing for such vision tasks (e.g., object detection, optical flow characterization). Moreover, we aim to reach higher information fidelity, without the noise induced by conventional capture and pre-processing processes, and at a much lower energy cost.

The ambitious long-term vision of the project is to develop the next generation AI paradigm that will eventually compete with deep learning. We believe that neuromorphic computing, mainly studied in EU countries, will be a key technology in the next decade. It is therefore both a scientific and strategic challenge for the EU to foster this technological breakthrough.

The consortium from four EU countries offers a unique combination of expertise that the project requires. SNNs specialists from various fields, such as visual sensors (IMSE, Spain), neural network architecture and computer vision (Uni. of Lille, France) and computational neuroscience (INT, France) team up with robotics and automatic control specialists (NTUA, Greece), and low power integrated systems designers (ETHZ, Switzerland) to help geoinformatics researchers (UNIWA, Greece) build a demonstrator UAV for coastal surveillance (TRL5). Adding up to the shared interest regarding analog-based computing and computer vision, all team members have a lot to offer given their different and complementary points of view and expertise.

Key challenges of this project are the end-to-end analog system design (from sensing to AI-based control of the UAV and 3D coastal volumetric reconstruction), energy efficiency, and practical usability in real conditions. We aim to show during that project that such a bioinspired analog design will bring large benefits in terms of power efficiency, adaptability and efficiency needed to make coastal surveillance with UAVs practical and more efficient than digital approaches.

The original event sensor that is being developed at IMSE is fully analog: it performs an analog pre-processing of the photocurrent generated by the illumination by computing the relative temporal changes of the illumination using fully analog circuits. The full temporal resolution enables continuous time, which is fundamentally different from standard frame-based cameras, where time is discretized, and data is acquired sequentially at every time step. The signal information is coded as events, later interpreted as spikes, that occur continously in time, in an analog fashion. The asynchronous signal from the sensor together with the asynchronous computation with the neuromorphic hardware are the most innovative aspect in our approach. Another key result is the foveation capability of the sensor, and the downstream algorithms that exploit this capability, namely a neuromorphic attention mechanism. Several attention models have been developed and implemented using SpiNNaker, Loihi, and Kraken. We have demonstrated that in a semantic segmentation task from using input events, the foveation could reduce the size of input data by a factor 3 while maintaining high performance results. Finally, a live demonstrator is under development, in the form of a UAV autonomously following a specific ground feature.

The consortium is composed of the following partners: University Côte d’Azur (FR), University of Lille (FR), University Aix-Marseille (FR), Instituto de Microelectrónica de Sevilla (Spanish Research Council and University of Seville, ES), University West Attica (GR), National Technical University of Athens (GR), ETH Zürich (CH). The project is coordinated by Jean Martinet (jean.martinet@univ-cotedazur.fr), and more information can be found on http://www.aprovis3d.eu.

3. Progress Report

3.1. Project objectives and activities implemented

(Indicative length: 2 pages per period)

Describe the work performed during each period and assess it with respect to the initial work plan. Clearly indicate who performed each part of the work and which parts are done in cooperation, describing the nature of the cooperation. Mention any difficulty encountered and the solutions implemented.

If applicable, indicate the work planned during the rest of the project, relating it to the initial work plan and the work already performed. Mention any open issue (e.g.: technical deadlock, service provider default, failure to meet deadlines, budget control), the solutions envisaged, and any foreseen need for a contractual project content revision or schedule extension.

FIRST PERIOD from April 1st, 2020, to March 31st, 2021:

During the first period from April 1st, 2020, to March 31st, the consortium has actively started to work on the project, despite the starting pandemic. The physical kick-off meeting, which was scheduled to happen in Prague, during CHIST-ERA Project Seminar 2020, has been cancelled and moved online. The online kick-off meeting has been organised in April 2020, and around 10 (mostly plenary) meetings in total have permitted a tight collaboration. We describe below partner-wise achievements, and collaboration inside the consortium.

At UCA, our main activities have been directed towards:

- the management of the project (orchestrate the Consortium Agreement, prepare the Risk Identification and Management Plan, the Data Management Plan), as a WP0L and Project coordinator,
- hire a PhD student (A. Gruel), from Oct. 2020, 6 months after the project start, in synchronization with PhD recruitment campaigns in France,
- start working on T3.1 “SNN-based machine learning adapted for DVS signals” and T3.2 “Event-based algorithm for depth detection”.

Besides, UCA and INT have started a collaboration in the form of co-supervision of 2 PhD students, including A. Gruel. Both PIs at UCA and INT co-supervise A. Gruel (UCA) and A. Grimaldi (INT).
During this period, UCA and NTUA have initiated a collaboration on the use of SNN and Reinforcement Learning for UAV control. Several bilateral meetings have been organised between PIs and PhD students from both sides to exchange knowledge and data.
Regarding the hardware, UCA has made a contact with S. Furber and SpiNNaker project at Manchester, to get access to remote SpiNNaker machines (for development) and borrow the SpiNN-3 boards and SpiNNaker chips (for deployment in the demonstrator). Sample boards and chips have been received and dispatched to INT, ETHZ, and NTUA/UNIWA. The other partners already possess SpiNNaker hardware. Besides, UCA has participated in a proposal coordinated by ETHZ of a project sent to Intel Neuromorphic Research Community (INRC), with the purpose of accessing Loihi API/hardware. The proposal was rejected, but an access will be granted. During the next 6 months, UCA will focus on T3.2, as a task leader.

U UL has participated to all project meetings and ongoing coordination of the writing of D1.1 and D1.2.1 with all partners. UL has recruited Mazdak Fatahi as engineer from March 2022 to February 2023. UL acquired in 2020 a SpiNN-5 machine on a local budget.

At INT, our main activities have been around the creation of the SNN algorithm and providing tools for effective collaboration:

- Recruitment of a PhD, Antoine Grimaldi, which started October 1st, 2020.
- Collaboration with UCA (co-supervision of 2 PhD candidates), with regular meetings (in visioconference during the pandemics, in person now).
- We developed a first model of object categorization using an end-to-end event-based approach.

This was accepted as a poster at the major computational neuroscience conference (COSYNE) and was submitted as a short paper to CBMI. The objective was to submit a full-length paper before 2021Q2.

- INT initiated the installation and maintenance of a data-sharing infrastructure on a privately owned server and domain name Spik.xyz. This server was allocated using funding from a previous source obtained by the consortium, under the coordination of INT, spikeAI. We have used this grant in 2019 to rent a 2x2To octo-core server hosted by OVH in Germany. INT installed an instance of nextcloud to provide a secure GDPR-compliant sharing platform internal to the consortium and not available to the public sphere. This server is intensively used to share administrative and collaborative documents but also to store and share the data acquired on the UAV (with about 215Go of acquired data at this moment).

During this period, IMSE has been studying different ways of coupling the event sensors' pixels. At a pixel level, a way of interconnecting individual pixels such that the combined output the pixel group responds to the temporal variation of the averaged photocurrent of the combined pixels has been devised. The combined output saves bandwidth with respect to the separate response of the individual pixels but keeps a meaningful signal. At an architectural level, several options peripheral circuitry to configure the foveal regions in a reconfigurable way with different levels of circuitry complexity and reconfigurability have been studied.
IMSE has designed the first small prototype of foveated event sensor. A digital implementation of the foveation scheme has been designed and simulated. Using this scheme, a foveated architecture has been proposed and a sensor prototype has been designed. The designed prototype is a 128x128 event sensor, where the foveal regions can be digitally programmed with no restrictions on the size nor on the number of foveation points. The prototype has been designed on AMS 0.35 mm technology and sent for fabrication on February 22nd, 2021.

During the initial project period, UNIWA has proposed a study case of mapping the coastal zone with the APROVIS3D UAV set-up. The proposed area is a small pocket-beach located in the South-eastern Attica in Greece, it is easily accessible for repeatability of experiments, and it offers considerable seasonal changes of its coastline. Furthermore, HCMR (Hellenic Center for Marine Research) is located onsite, offering the possibility of static monitoring event camera setup to capture extreme weather events (beach before and after a sea storm). UNIWA also announced one PhD position, which has been filled in March 2021. In particular, the selected candidate will work on mapping of the coastal areas to be carried out with the APROVIS3D bio-inspired camera set-up, and with the aim of monitoring the wave field, as well as the 3D representation of the coastline and coastal zone. Vision data will follow processing and classification algorithms for a more complete 3D representation of the coastal environment, to be then compared to conventional surveys, and to be used for the calibration of field data. Finally, the possibility of using the APROVIS3D vision data in coastal engineering models will be also assessed.

The NTUA team is leading WP5: Demonstration and validation and participates in WP0, WP1, WP2, WP3, WP4 and WP6. Task 5.1: Servoing: interfacing of analog vision and UAV started on M10, while Task 5.2: Field data collection and T5.3 Benchmarking and validation will both start at M16. During the first 12 months of the project, NTUA recruited a new PhD Student (Sotirios Aspragkathos). However, the official hiring has not yet completed, since the budget is not yet released for NTUA. A summary of NTUA activities during this period includes: i) An extensive study of the current state of the art related to vision-based control of multi-rotor vehicles, employment of event cameras in motion control and vision-based detection and tracking of segment-based outdoor areas (e.g. coastlines), ii) Development of a realistic simulation environment in ROS/Gazebo as a supporting tool, iii) Training of a Convolutional Neural Network (CNN) in order to perform real-time detection of a coastline iv) Development of online vision-based motion estimation algorithm for the coastline, v) Development of a visual servoing strategy for coastline tracking using an unmanned aerial vehicle (paper submitted in IEEE/RSJ IROS 2021), vi) Preliminary design of an image-based visual servoing non-linear model predictive control scheme (IBVS-MPC) for coastline surveillance, vi) Parallel collaboration with UCA for the employment of Reinforcement

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learning in coastline detection and tracking tasks using a UAV. All the performed activities are in line and in support of the three WP5 Tasks. In the next 12 months, NTUA will proceed according to the project plan. Unfortunately, by the time this report was written funding was not yet released to NTUA, resulting in the delay of the equipment purchase (UAV, etc.) and the official hiring of the PhD Student.

During the first period, ETH started the investigation of the hardware and software subsystem for the final system integration. For the hardware, ETH participated to the hardware selection of the neuromorphic processor. Furthermore, ETH started to work with the novel Intel Loihi neuromorphic processor to test and evaluated the performances. The neuromorphic processor will be also benchmarked to have a fair comparison with another processors (i.e., ARM Spinnaker). On the software side, a comparison of different frameworks has been performed with a testbed based on an open dataset of gesture recognition with event cameras. Finally, ETH has started to work with a preliminary event sensor provided by IMSE.

The consortium takes the opportunity of this report to point out some deviations from the initial schedule: due to the interdisciplinary nature of the consortium, some extra discussion time has been necessary to converge to a shared vision of the functional and technical requirements, which explains the late release of D1.1 and D1.2.1. In a recent discussion (30/3/2021), the consortium has re-discussed over both deliverables, and brainstormed to make sure that the project is going in the right direction. Another iteration will be necessary to reach the final definition of the demonstrator in D1.2.2.

The consortium is currently pursuing directions of research in order to meet the next milestone in Fall 2021 where all core components (stereo-event sensing, SNN-ML, system architecture) will be ready for integration.

SECOND PERIOD from April 1st, 2021, to March 31st, 2022:
During the second period, UCA has kept actively coordinating the consortium. Several main plenary consortium meetings (8) have been organised during the period, in addition to other side technical meetings. UCA participated to CHIST-ERA project seminar on April 12-14, 2021, as a representative partner for APROVIS3D, and also was the speaker for ACAI 2018 topic during the joint topic plenary restitution. Besides, UCA has coordinated the edition of short video advertising APROVIS3D. The plenary discussions in the consortium have included feedback on Periodic report for period 1, and recommendations given during CHIST-ERA project seminar. An extension request for months was submitted to CHIST-ERA at the end of Period 2, in the name of the consortium.
UCA has mainly worked on (1) T2.2 Event-based Stereopsis with the design of an event stereo prototype – namely after the intern work of S. Ballerio during Summer 2022 – and writing of D2.2.1, and (2) and T3.2 Event-based algorithm for depth detection, with the development of an event stereo system inspired from [Dikov, 2017]. An intern student (H. Han) was hired during Summer 2021 to work on the stereo system, allowing the algorithm to use a pre-recorded stereo event stream with a small resolution (22x22) to estimate the depth using a single SpiNN-3 board.
Because of the unexpected delay in the design of the foveated sensor (due to the pandemic and shortage of semi-conductors, see below), UCA has worked with IMSE on a software-simulated foveated sensor, where low-resolution and high-resolution events can be selected and arranged according to a foveation map. The first step is to generate low-resolution data based on high-resolution. Several techniques have been investigated in [Gruel et al., ORASIS 2021, Gruel et al., VISAPP 2022] and also their complexity and runtime on neuromorphic hardware [Gruel et al., ICIP 2022-submission, Gruel et al., 2022-submission]. These 2 publications and 2 submissions are the result of a joint work between UCA and IMSE.
In November 2021, UCA (J. Martinet and A. Gruel) made a short visit to ETHZ with the purpose of neuromorphic hardware experimental validation of a visual attention mechanism [Gruel et al., AICAS 2022-to appear].
The end of the second period has seen active exchanges between NTUA, INT, and UCA towards the development of an SNN model for coastline detection. Two short exchange visits have been organized for PhD students between UCA and INT in March-April 2022.

During the second period, UL has participated to all consortium meetings, and participated to the overall effort. UL explores the possibility to convert CNN to SNN, and to run then using both hardware platforms considered in the project (SpiNNaker and Loihi). In agreement with the developments plan of the work, UL has recruited a research engineer (M. Mazdak Fatahi) from March 1st, 2022. Therefore, UL expects a stronger contribution during the last period, where the project will need efforts for implementation, integration, and benchmarking.

INT has further extended the work done in the first period. As planned, we have extended the work presented in the short paper submitted at CBMI by 1/ extending the results to a larger palette of existing datasets, 2/ bridging the neuromorphic algorithm with the building blocks which form Spiking Neural Networks. This last point has the direct consequence that the categorizations or decisions made by the algorithm can be performed at any instant in time, an important asset for robotics applications. These results were written down in a full-length paper which was submitted to IEEE Transactions on Pattern Analysis and Machine Intelligence (PAMI). It is in now in the process of being re-submitted after a first round of review requesting for a revision and available as a preprint.
While these theoretical results are quite general and applied on a set of State-Of-The-Art benchmarks, a second major direction taken by INT during that period was to adapt this algorithm to the problem which has to be solved in the APROVIS3D project. We mainly focused on the ultra-rapid detection of the coastline which will be essential for guiding the UAV. For this, we have extensively collaborated with NTUA to collaboratively define the dataset. We have started by synthetic data as acquired using the Gazebo platform. In a second step, we have contributed collaboratively with UCA to define the dataset that has been acquired by NTUA in realistic conditions. In particular, this has led to better evaluate the difficulty of the task, in particular with respect to the diversity of coastline types and meteorological conditions encountered by the UAV. In particular, we have developed an ultra-fast Elementary Motion Detector (EMD) which will help compensate for the variability in motion generated by the UAV and improve classification performance. In particular, thanks to in person visit between INT (in Marseille, France) and UCA (in Sophia Antipolis, France), we have further advanced the collaboration notably to bridge the theoretical model developed by INT to its implementation on a neuromorphic SNN board by UCA. Our objective is to describe this novel algorithm in a multi-partner full-length publication between NTUA, UCA and INT.

As for the activities of IMSE, due to the crisis of supplies in the microelectronics sector, the AMS fabricated chip was received in November 2021. In the meantime, a PCB with external circuitry for biasing, configuring and externally controlling the chip foveation was designed. Once the fabricated sensor was received and it was verified that the chip package matched correctly into the designed PCB, the test PCB was ordered for fabrication. The PCB with the mounted components was received in March 2022. IMSE is now beginning to test the sensor.
In parallel, the XH180nm technology from XFAB is being studied as alternative technology to fabricate a higher-resolution prototype. This technology has optimized photodiodes for visible light, 6 metal layers and MIM capacitors as well as smaller transistors, which can be an alternative to build more compact pixels. An event pixel has been designed in this technology. The size of a 2x2 array of dvs pixels in the xfab 0.18 technology is 35.1 um x35.85um, so that a pixel occupies approximately ¼ the area of the pixel in the AMS0.35 technology. Thus, IMSE expects to be able to design a foveated sensor of at least 256x256 resolution in the XFAB technology within a similar area to the already fabricated AMS0.35micron sensor.
A first 32x32 test prototype of foveated DVS in the XH018 technology is being designed and will be submitted for fabrication in May 2022.
IMSE has also contributed to the theoretical study of algorithms for reducing the sensor resolution in collaboration with the UCA partner.

During the second period, UNIWA hired a PhD student (Ioannis Kourliaftis) along with the purchase of the required consumables and equipment update for prototyping machine, which is going to be used for the production of the final board prototypes for the UAV platform. The UNIWA team also investigated the coastline detection testing areas that can be suitable for the demonstration of the final prototype and in line with the deliverables from WP4 and WP5

During the past 12 months of the project, the budget was released for NTUA, and the hiring of the PhD Student (Sotirios Aspragkathos) along with the purchase of the vehicle that will serve the needs of the project went through. A summary of the NTUA activities during this period includes: i) Setup of the UAV (octorotor) in which the demonstration scenario of the vehicle will take place, establishing the communication between the internal controller of the vehicle with the onboard PC (NVIDIA Jetson AGX Xavier Developer Kit) aiming at the autonomous flight, ii) An extensive study of the current state of the art related to event-triggered model predictive visual servo control able to handle asynchronous feedback data from a Dynamic Vision Sensor (DVS), iii) Multiple sessions of DVS field data were collected during flight of the UAV above the coastline and shared with the consortium, iv) Establishment of the HW and SW interface between the IMSE DVS prototype, the SpiNN-3 board and the vehicle's onboard PC (NVIDIA Jetson AGX Xavier Developer Kit), v) Experimental validation of the developed visual servoing strategy for coastline tracking using an unmanned aerial vehicle (paper submitted in 30th Mediterranean Conference on Control and Automation 2022), vi) Development of a robust event-triggered vision based model predictive controller for coastline tracking using a multirotor which was experimentally validated (paper submitted in IEEE/RSJ International Conference on Intelligent Robots and Systems 2022), vii) Parallel collaboration with UCA and INT for the development of a newly trained SNN for coastline detection which will be utilized in coastline tracking applications using the UAV. All the performed activities are in line and in support of the three WP5 Tasks. In the next 12 months, NTUA will proceed according to the project plan.

During the second period, ETHZ focused on the implementation of a multi-object detection spinking algorithm on Intel Loihi in collaboration with UCA. In autumn 2021 a visit from UCA has been organized and hosted to work in collaboration on the algorithm and its implementation. The results of this collaboration have been included in a recent publication at IEEE AICAS 2022 and it will be presented at the conference in June 2022. ETH also collaborated with IMSE to support the connection with Spinnaker of their camera and use the DVS Camera to extract samples. Finally, ETHZ worked on the system architecture definition for the final prototype of the drone that will be included the IMSE camera, a neuromorphic platform with one of the 2 current adopted neuromorphic processors SpiNNaker and Intel Loihi, and the control unit based on standard digital hardware such the NVIDIA jetson.

THIRD PERIOD from April 1st, 2022, to December 31, 2023 (extended final period of 20 months):
During the third and final period, UCA continued the coordination of the project. The consortium started to organise physical meetings after the lifting of travel restrictions in countries of the partners. UCA participated to CHIST-ERA project seminar on March 28-30, 2022, as a representative partner for APROVIS3D. During this period, due to a consecutive slowdown in the realisation of the demonstrator, the whole consortium submitted to CHIST-ERA an extension request until 31/12/2023, that has been granted by CHIST-ERA and to all partners. An update version of the DMP (for T0+24M) was submitted in September 2022, within the 6-month delay of the initial extension. During an Executive Committee meeting organised by UCA in June 2022 to discuss the funding situation of the Greek partners and the subsequent slowdown in realisation of the demonstrator, the decision was taken to postpone the final event from July 2023 to September 2023. The project final event took place at IMSE on September 14-15, 2023. The consortium has organised an industrial session with several companies (Inivation, Sony, Yumain, IMRA Europe, Renault Software labs, Synsense, Ucandrone) that came for two online sessions: one session where the companies have been offered the opportunity to pitch their products, and one session where the consortium did advertise the main project results to the companies. This session was a success for all. UCA has participated in finalising the demonstrator with activities (1) on a simple 3D (ground) demonstrator using Prophesee cameras acquired on another UCA budget, and a host laptop connected to the cameras and a SpiNN-3 board), and (2) on the main flying demonstrator finalized by NTUA, UL, and INT. A dataset acquired by UCA with a commercial drone has been used for training the SNN ML models. Besides, during the visit of the IMSE PhD student Mrs. Farnaz Faramarzi to UCA for 6 weeks in November-December 2023, we carried out developments for implementing SNN attentional mechanisms on IMSE foveated sensor. The timeline of

the development did not allow us to port this development to the final main demonstrator. Finally, UCA carried out the final coordination action points by ensuring that all final deliverables are ready and delivered before the project end.

During the third period, INT has further extended the work done in the second period. The algorithm in the form of a Spiking Neural Network that was presented at CBMI was extended by 1/ applying the results to a larger palette of existing datasets, 2/ bridging the neuromorphic algorithm with the building blocks which form Spiking Neural Networks. This last point has the direct consequence that the categorizations or decisions made by the algorithm can be performed at any instant in time, an important asset for robotics applications envisioned in the APROVIS3D project. These results were written down in a full-length paper which was submitted to Neural Networks. It is in now in the process of revision after a first round of reviews and available as a preprint. While these theoretical results are quite general and applied on a set of State-Of-The-Art benchmarks, a second major direction taken by INT during that period was to adapt this algorithm to the problem which has to be solved in the APROVIS3D project. We mainly focused on the ultra-rapid detection of the coastline which will be essential for guiding the UAV. For this, we have collaborated with NTUA to collaboratively define the dataset. In a second step, we have contributed collaboratively with UCA to define the dataset that has been acquired by NTUA in realistic conditions. In particular, this has led to better evaluate the difficulty of the task, in particular with respect to the diversity of coastline types and meteorological conditions encountered by the UAV. In practice, we have shown that the algorithm achieves very good accuracies in patch-based segmentation, and that the configuration of these paths (notably their size and position in sensor space relative to the direction of the UAV) should be further explored. Thanks to in person visits between INT (in Marseille, France) and UCA (in Sophia Antipolis, France), we have further advanced the collaboration notably to bridge the theoretical model developed by INT to its implementation on a neuromorphic SNN board by UCA. Our objective is to describe this novel algorithm in a multi-partner full-length publication between NTUA, UCA and INT.

A summary of the NTUA activities during this period includes: i) implementation of a hybrid MB/DD approach for the coastline motion estimation. The actual multirotor velocity, The estimated errors are incorporated as feedback into a PVS planning and tracking control scheme to achieve the octorotor's autonomous vision-based navigation along a shoreline, ii) iv) experimental validation of the developed visual servoing strategy for coastline tracking using an unmanned aerial vehicle (paper published in MDPI Drones Special Issue on UAVs for Coastal Surveying), ii) utilization of an event-based Neuromorphic implementation of the Hough Transform on a neuromorphic chip (SpiNN-3 board) for line detection, ii) development of a tracking algorithm with conventional computing (NVIDIA Jetson AGX Xavier Developer Kit), iv) design, development and testing of the visual servoing algorithms that will be able to handle event-based asynchronous data deriving from the DVS configuration and the SNN detection algorithms, v) experimental validation of the developed visual servoing strategy for pavement tracking using an unmanned aerial vehicle (paper submitted in IEEE/RSJ International Conference on Intelligent Robots and Systems 2023), vi) Parallel collaboration with UCA and INT for the development of a newly trained SNN for coastline detection which will be utilized in coastline tracking applications using the UAV.

The efficacy of the proposed framework is demonstrated through a series of outdoor experiments in various environment sets deploying a custom-made octorotor equipped with an asynchronous perception system, an onboard computer (NVIDIA Jetson AGX Xavier) and a Pixhawk Cube Orange featuring ArduPilot firmware. The perception system consists of a DVS and a hybrid computing system, a combination of SpiNN-3 neuromorphic computing platform and the onboard computer. The vision sensor communicates with the computing system with a custom optimized VLSI design running on an FPGA board to avoid latency. SpiNN-3 board is used to implement the core of the contour detection algorithm, using the Hough Transform. The onboard computer is used to run the tracking algorithm on the outcome of the SpiNN-3 board and simultaneously the event-based PVS control strategy using the Robot Operation System ROS. The MAVROS communication protocol is used to send the velocity commands produced by the PVS control scheme to the octocopter's microcontroller. The low-level control of the octocopter is used to handle the Pixhawk's velocity commands.

Recently, the possible development of a model as a descriptor of our target, which is the coastline, has been investigated with the aim of better integrating its variable elements into the controller for optimal performance. At the same time, the IROS 2023 submitted paper was accepted and presented at the conference contributing to the dissemination of the achievements of the APROVIS3D project. Finally, between November and December 2023, flights were carried out on beaches in collaboration with the partners from UNIWA and UL. Initially for data collection for topographical and geomorphological purposes and then for further data acquisition for the development of an SNN-based coastline detection algorithm.

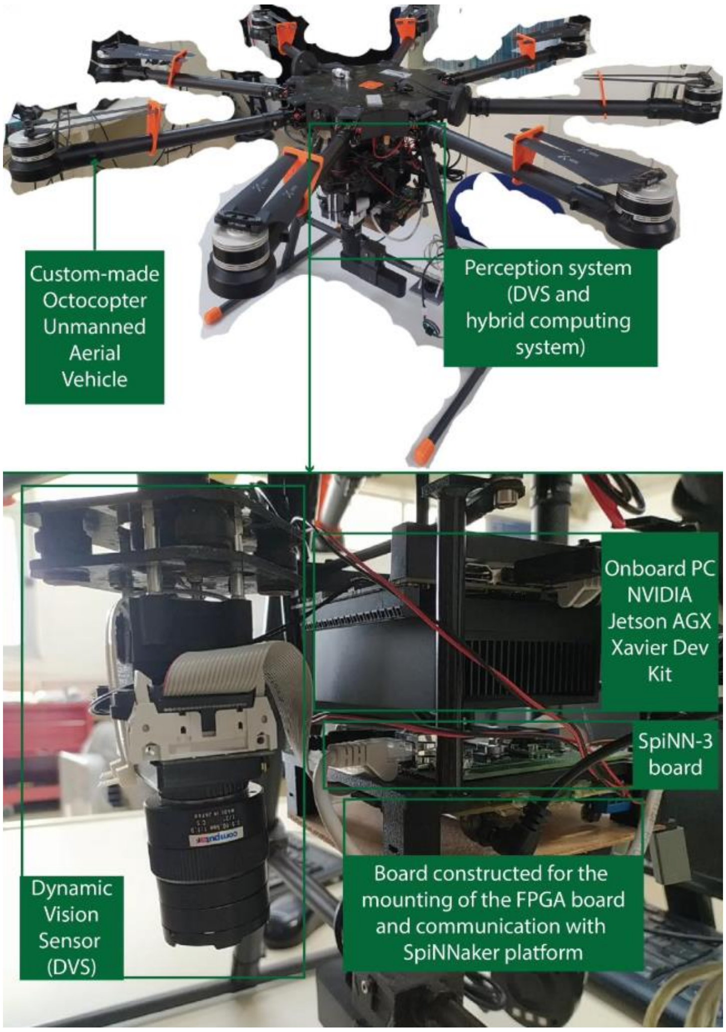
During the third period, ETH is working on implementing and designing spiking neural network algorithm for event-based data on real platform such as the Intel Loihi Platform and the ETH system on chip Kraken. The results of the work done have been submitted in two papers at IEEE Artificial Intelligence Circuits and Systems AICAS 2023 and IEEEE international Joint Conference on Neural Network IJCNN 2023, both papers are done in collaboration with UCA. Another task of this period was the design and development of the first fully medium size UAV neuromorphic platform done around the Kraken system on chip. The design and implementation with preliminary energy and power results are published and presented in the 9th IEEE International Workshop on Advances in Sensors and Interfaces (IWASI 2023).

During the third year, IMSE has developed the code for the microcontroller embedded in the PCB of the 128x128 EF-DVS. A Graphical User Interface (GUI) has also been developed. From the Graphical User Interface, the current and voltage biases of the sensor can be controlled. Furthermore, from the GUI, the user can configure the sensor in high resolution, or in low resolution with rectangular low-resolution regions of *n x m* pixels as determined in the GUI. In the low-resolution configured sensor, high-resolution regions of different centers and sizes can also be configured. Additionally, IMSE has worked on real-time tracking algorithms that can be implemented in the microcontroller or in an external programmable FPGA that can allow the automatic real time control of the regions of interest. IMSE has also worked on the extensive characterization of the optical and electrical characteristics of the sensor in different foveal configurations. Finally, IMSE has completed the design of a 64x64 EF-DVS in the XFAB 0.18 technology.

UL has been involved in the development of the spiking neural network for coastline detection and its test on real data on a SpiNNaker board with INT, UCA and NTUA.

Note about the deliverable systems of the project.
We provide here some illustrations of the deliverables system, that are described in this report and more precisely in specific deliverable reports from target WPs.

D2.2.2: Stereo System, with standard non-foveated sensors



D4.3: Working prototype and

3.2. Transnational collaboration

Describe the added value and synergies in the collaboration, any obstacles to the transnational collaboration, and the proposed solution (if necessary).

The APROVIS3D consortium offers a unique European combination of expertise for implementing the key technologies that the project requires.

- IMSE partner in Spain develops non conventional video sensors mimicking mammal's visual system with stereo and foveal features
- UCA, UL, and INT in France develop computer vision algorithms dedicated to this sensor, taking inspiration from computational neuroscience
- ETHZ in Switzerland takes care of system integration with low-power hardware
- NTUA in Greece hosts robotics and control specialists for interfacing the vision system with the navigation system
- Geoinformatics experts at UNIWA in Greece will exploit this embedded system in the coastal monitoring use cases

The following collaborations were ongoing during Period 1:
IMSE was collaborating with ETHZ partner. IMSE has sent to ETHZ an event sensor prototype designed in a previous project by IMSE so that ETHZ can experiment and develop the circuitry to read out the output event from the event sensor and the communication with a PC.

The NTUA has been collaborating with all the partners, participating in technical meetings, discussions, and exchange of ideas for all WPs. For the initial 12 months a specific scientific collaboration has been launched with UCA, aiming to the employment of Reinforcement learning for coastline detection and tracking using a UAV. Several side meetings have been carried out between NTUA and UCA and both teams will work towards a joint publication.

Regarding the access to Intel's Loihi, UCA has encountered for several months since October 2020 a deadlock in the legal negotiations between legal entities. ETH did not experience the same deadlock. One proposed solution to bypass this obstacle is to organize one or several short visits by UCA staff to ETH during Summer 2021 or Fall 2021, if needed. The agreement between UCA and Intel was finally signed in May 2021.

The following collaborations were ongoing during Period 2:
During the past 12 months a specific partnership between UCA and INT has been established with the goal of developing a newly trained SNN for coastline detection that will be used in UAV-based coastline tracking applications. NTUA, UCA, and INT have held a number of side meetings, and both teams are working on a joint publication.

IMSE is collaborating with NTUA partner. IMSE has also sent to NTUA an event sensor prototype that has been already mounted on a drone by the NTUA partner.
IMSE has also cooperated with UCA by studying different mechanisms for reducing the peripheral information of a pixel group in a foveated vision sensor. Three joint conference papers have been published under this cooperation.

A 5-day visit of UCA (J. Martinet, A. Gruel) to ETHZ has been organized in November 2021.

The end of the second period has seen active exchanges between NTUA, INT, and UCA towards the development of an SNN model for coastline detection.

The following collaborations are ongoing during Period 3:
The PhD student A. Gruel (UCA) visited ETHZ during 3 weeks during August 2022.
A 5-day visit of J. Martinet and A. Gruel (UCA) to ETHZ was organized in November 2022.
The PhD student A. Grimaldi (INT) visited the lab of Martin Vinck from September to December 2023.
The PhD student A. Gruel (UCA) visited IMSE during 4 weeks during December 2022.
The PhD student F. Faramarzi (IMSE) visited UCA for 6 weeks in November-December 2023 (from 13/11/2023 to 22/12/2023).

NTUA has been collaborating with all the partners, participating in technical meetings, discussions, and exchange of ideas for all WPs. During the past 12 months a specific partnership between UCA and INT has been established with the goal of developing a newly trained SNN for coastline detection that will be used in UAV-based coastline tracking applications. NTUA, UCA, and INT have held several side meetings, and both teams are working on a joint publication. Also, a joint paper with IMSE has been accepted for publication and presented in IEEE/RSJ International Conference on Intelligent Robots and Systems 2023 in October 2023. Finally, between November 2023 and December 2023, flights were carried out on beaches in collaboration with the partners from UNIWA and UL. Initially for data collection for topographical and geomorphological purposes and then for further data acquisition for the development of an SNN-based coastline detection algorithm.

3.3. Significant events and results

(Indicative length: 2-4 pages)

Describe the main achievements of the project. For example:

- *New ideas, new knowledge, new interpretative models of complex phenomena;*
- *Realization of new scientific instrumentation and/or advanced devices;*
- *Implementation of new advanced scientific methodologies;*
- *Realization of prototypes;*
- *Proposal of new technologies;*
- *Contribution to innovation in the production of goods and services;*
- *Development of innovative software;*
- *Economic impact and results exploitation.*

For each achievement, provide a description with factual and, if relevant, quantitative information.

FIRST PERIOD from April 1st, 2020, to March 31st, 2021:
During the first 12 months, UCA has started working on T3.1 “SNN-based machine learning adapted for DVS signals” and T3.2 “Event-based algorithm for depth detection” during Summer 2020 with two intern students: S. Ballerio on event stereo matching, and R. Mosca on R-STDP for image feature recognition and robot control.

The aim of the work with S. Ballerio was disparity estimation with stereo event cameras. UCA has purchased a pair of QVGA event cameras from Prophesee (on a spare budget, for the purpose of another project). The objective is to avoid frame reconstruction because it adds delay and yields errors. We used time surfaces [Lagorce, PAMI 2017], with an exponential decay kernel to keep recent time history. In the work, we have tried to adapt and extend to event a stereo matching algorithm for RBG images, PatchMach Stereo [Bleyer, BMVC 2011] with slanted support windows – inspired from PatchMatch [Barnes, SIGGRAPH 2009] for region matching. In this preliminary work, we have observed that it is hard to tune the time constant (tau) that sets the exponential decay, because if it is set too small, the data will be sharp but scares (only little information), and if it is too large, the data will be dense but noisy. A masking strategy has been proposed to keep the most precise information available, with unconvincing results.

The aim of the work with R. Mosca was to exploit SNN and Reinforcement Learning for in two scenarios: feature extraction and robot control. The feature extraction part is inspired from Multiscale Spatio-Temporal features MuST [Liu, TNNLS 2020], with a HMAX-like architecture. The proposed approach, dubbed ReMus *Reinforced Multiscaling*, defines an STDP learning rule with RL, inspired from [Mozafari, TNNLS 2018]. Mozafari's work enables binary classification of grayscale images. In their work, a silence (no output spike) is a valid prediction, which yields no weight update, creating a "dead neuron" problem. The objective of ReMus is to extend Mozafari's for event data, and multiclass classification. The robot control part is inspired from [Bing, ICRA 2018], and extends Braitenberg vehicles. A simulated demonstration has shown interesting results in object following and line following scenarios. We have learnt from this work that it will not be straightforward to distinguish the sea from the shore, which would be useful in our project use cases.

This work is unfinished, and both directions will continue with A. Gruel (PhD student recruited at UCA from Oct. 2020), and with the new collaboration with NTUA. A. Gruel has published a local poster during the inauguration of Neuromod institute related to the use of attention model for event cameras, based on [Bernert, IJNS 2019], in the perspective of exploiting the foveated sensor developed by IMSE, and recently submitted a paper to CBMI'2021 on the same topic.
Based on a previous extra-consortium collaboration developed with the Institut de la Vision in Paris, INT started working on T3.1 "SNN-based machine learning adapted for DVS signals". Inspired from a study [Lagorce, PAMI 2017] on a pattern recognition algorithm developed for event-based signals, INT applied a simple homeostasis rule, inspired by living systems, on the existing method. A bridge between event-based algorithms and bio-inspired SNN was introduced theoretically. This work was accepted at the major computational neuroscience conference (COSYNE) and was submitted as a short paper to CBMI'2021. The continuity of this work is achieved by developing an end-to-end object categorization model achieving good results after only few events. This method is tested on various datasets including real scenes captured by event sensor and is to be published in a full-length paper before 2021Q2.

During these months, IMSE has been studying different ways of coupling the event sensors' pixels. At a pixel level, a way of interconnecting individual pixels such that the combined output the pixel group responds to the temporal variation of the averaged photocurrent of the combined pixels has been devised. The combined output saves bandwidth with respect to the separate response of the individual pixels but keeps a meaningful signal. At an architectural level, several options peripheral circuitry to configure the foveal regions in a reconfigurable way with different levels of circuitry complexity and reconfigurability have been studied.

During the first 12 months, the NTUA team developed a realistic simulation environment in ROS/Gazebo as a supporting tool, featuring a configurable coastline environment, a multi-rotor UAV equipped with various perception (e.g., stereo camera, event sensors) and navigation (e.g., GPS, IMU) sensors as well as a Software In the Loop (SITL) autopilot system. The synthetic environment was initially used for coastline data collection. The collected frames were used for pre-processing and training of a Convolutional Neural Network (CNN) in order to perform real-time detection of a coastline. Based on the successful detection, a visual servoing strategy for coastline tracking using an unmanned aerial vehicle was developed and its efficacy was demonstrated via realist simulation tests. An on-line estimation algorithm for the wave-induced motion of the coastline, was designed, implemented, and incorporated in the visual servoing scheme, resulting in reduced tracking errors. The resulting work so far was submitted in IEEE/RSJ IROS 2021 Conference for possible publication. Additionally, the NTUA team performed a preliminary design of an image-based visual servoing non-linear model predictive control scheme (IBVS-MPC) for coastline surveillance. The IBVS-MPC is currently tested on the simulator. Alongside, a parallel collaboration with UCA has been launched, aiming to the employment of Reinforcement learning for coastline detection and tracking using a UAV.

ETHZ investigated on the implementation of SNN on the neuromorphic processor from Intel called Loihi. In particular, it has been used for a gesture recognition dataset from IBM acquired with an event camera and different toolkits (i.e., Nengo and Slayer among others) has been used and benchmarking. The integration plan will investigate on the possibility to process data with a neuromorphic processor (ARM SpiNNaker or Intel Loihi) directly from the event camera provided by IMSE, and output will be used by NTUA to control the UAVs. Both Spinnaker from ARM and Intel Loihi will be evaluated.

SECOND PERIOD from April 1st, 2021, to March 31st, 2022:
UCA has mainly worked on (1) T2.2 Event-based Stereopsis with the design of an event stereo prototype – namely after the intern work of S. Ballerio during Summer 202 – and writing of D2.2.1, and (2) and T3.2 Event-based algorithm for depth detection, with the development of an event stereo system inspired from [Dikov, 2017]. An intern student (H. Han) was hired during Summer 2021 to work on the stereo system, allowing the algorithm to use a pre-recorded stereo event stream with a small resolution (22x22) to estimate the depth using a single SpiNN-3 board.
Because of the unexpected delay in the design of the foveated sensor (due to the pandemic and shortage of semi-conductors), UCA has worked with IMSE on a software-simulated foveated sensor, where low-resolution and high-resolution events can be selected and arranged according to a foveation map. The first step is to generate low-resolution data based on high-resolution. Several techniques have been investigated in [Gruel et al., ORASIS 2021, Gruel et al., VISAPP 2022] and also their complexity and runtime on neuromorphic hardware [Gruel et al., ICIP 2022-submission, Gruel et al., 2022-submission]. These 2 publications and 2 submissions are the result of a joint work between UCA and IMSE.
In November 2021, UCA (J. Martinet and A. Gruel) made a short visit to ETHZ with the purpose of neuromorphic hardware experimental validation of a visual attention mechanism [Gruel et al., AICAS 2022-to appear].

IMSE has designed a prototype of foveated dynamic vision sensor of 128x128 resolution in AMS 0.35micron OPTO technology (under test).

During the past 12 months, the NTUA team has dealt with the following: i) setup of the aerial platform with the aim of being ready for any kind of flight sessions (field data collection or validation of proposed control methods), ii) Development and validation of vision-based control strategies for coastline tracking using the UAV and that can incorporate the DVS in the future, iii) communication establishment between DVS prototype and SpiNN-3 board and mounting of the setup on the UAV. The setup of the vehicle requires the trouble-free communication between its controller (Pixhawk Cube Orange) and the onboard PC (NVIDIA Jetson AGX Xavier Developer Kit) in which all the necessary calculations are performed and through the ROS software commands are given to the rotors. Based on the ready to go aerial platform we examined the experimental validation of the visual servoing strategy for coastline tracking using a UAV through autonomous experimental sessions on real coastlines. surveillance of coastlines using an octocopter aerial vehicle is proposed. The implemented strategy is focused on the vision-based detection and tracking of dynamic coastlines and in the presence of waves while flying in low altitudes. For this purpose, a Deep Neural Network (DNN) for the detection of the coastline is employed. The DNN is accompanied by an analytical formulation of an Extended Kalman Filter (EKF), which considers an approximate periodical wave motion model to provide an online estimate of the coastline motion directly in image space. The estimated feedback is provided to an appropriately formulated IBVS tracking controller for the autonomous guidance of the octocopter along the coastline, ensuring the latter is always kept inside the camera's field of view. The resulting work so far was submitted in MED 2021 Conference for possible publication. Additionally, the NTUA team performed the development of a robust event-triggered vision based Nonlinear model predictive controller for coastline tracking using an unmanned aerial vehicle. In an effort to reduce the remarkably large computational cost required by an IBVS-NMPC algorithm, a triggering condition is designed to define when the Optimal Control Problem (OCP) should be resolved, and new control inputs will be calculated. Between two successive triggering instants, the control input trajectory is applied to the robot in an open-loop way, which means no visual measurements or control input computations are required at that moment. This result work so far was submitted in IEEE/RSJ IROS 2022 Conference for possible publication. In order to experimentally test future DVS schemes, the NTUA team also established the HW and SW interface between the IMSE DVS prototype, the SpiNN-3 board, and the vehicle's onboard PC. The communication between all of them is performed via an FPGA board and it is possible for the information collected by the DVS to be routed to the onboard PC after it has been processed by the SpiNN-3 board. In addition, a parallel collaboration with UCA and INT has begun, with the goal of employing a newly trained SNN for coastal identification and exploitation in UAV-based coastline monitoring applications.

During the past 12 months, UNIWA constantly supports dissemination activities and made the necessary preparations for the successful application of final demonstrator. More specifically, UNIWA purchased and configured all the materials and consumables that are necessary for the production of the PCB boards for the final prototypes of the UAV custom-made circuits. In addition, UNIWA constantly investigates and evaluates the testing areas to have a smooth and productive demonstrator case in terms of environmental and field surveying factors.

ETHZ has mainly worked on the system architecture definition that will be the core topic of the WP4 and the Task 4.1 and the deliverable D.4.1 that is currently been written. Moreover, ETH is working on WP4 Task 2 for the implementation on a spiking NN algorithm on Intel Loihi.

THIRD PERIOD from April 1st, 2022, to December 31, 2023 (extended final period of 20 months):
During this period, UCA has continued and intensified the work and collaborations around the project. In August 2022, A. Gruel (UCA) went to ETHZ for a 3-week visit, from 15/08/2022 to 02/09/2022. In November 2022, UCA (J. Martinet and A. Gruel) made a second short visit to ETHZ with the purpose of working on visual attention models (extension to multiple objects) and their implementation on ETHZ neuromorphic chip, resulting in two publications [Gruel et al., AICAS 2023, Gruel et al., IJCNN 2023] in collaboration with ETHZ. After this visit, A. Gruel has had the opportunity to visit IMSE for a 4-week visit (28/11/22-23/12/22), to work on algorithms for the foveated sensor. The resulting work done during this period has been accepted for publication in [Gruel et al., CVPRw 2022, Gruel et al., WACV 2023, Gruel et al., Biological Cybernetics] with IMSE. The last publication is also in collaboration with INT. Besides, UCA has collaborated to the publication [Grimaldi et al., Brain Science 2022] with INT. Finally, during the visit of the IMSE PhD student Mrs. Farnaz Faramarzi to UCA for 6 weeks in November-December 2023, we carried out developments for implementing SNN attentional mechanisms on IMSE foveated sensor.

During the reported period, the National Technical University of Athens (NTUA) undertook various research activities in the field of unmanned aerial vehicle (UAV) navigation and computer vision. One of the primary endeavors was the implementation of a hybrid MB/DD (Model-Based/Data-Driven) approach for coastline motion estimation. This approach utilized the actual multirotor velocity and estimated errors, which were incorporated as feedback into a PVS planning and tracking control scheme to achieve the octocopter's autonomous vision-based navigation along a shoreline.
Furthermore, the experimental validation of the developed visual servoing strategy for coastline tracking using a UAV was another significant achievement. A paper detailing the methodology and results was published in the MDPI Drones Special Issue on UAVs for Coastal Surveying. This research represents a step forward in the development of vision-based systems for coastal surveying applications.
In addition to the above, NTUA also utilized an event-based neuromorphic implementation of the Hough Transform on a SpiNN-3 board for line detection. This approach demonstrated the effectiveness of utilizing neuromorphic hardware for computationally intensive vision tasks. Moreover, the development of a tracking algorithm using conventional computing, specifically the NVIDIA Jetson AGX Xavier Developer Kit, was another noteworthy achievement.
NTUA also focused on the design, development, and testing of visual servoing algorithms that could handle event-based asynchronous data derived from the DVS (Dynamic Vision Sensor) configuration and the SNN (Spiking Neural Network) detection algorithms. This combination of conventional and neuromorphic computing allowed for the development of efficient and effective visual servoing algorithms that could handle event-based data.
Another experimental validation of the developed visual servoing strategy for pavement tracking using a

UAV was conducted, and a paper detailing the methodology and results was submitted to the IEEE/RSJ International Conference on Intelligent Robots and Systems 2023. This research represents a significant contribution to the field of vision-based systems for pavement tracking applications.
Lastly, NTUA collaborated with UCA and INT for the development of a newly trained SNN for coastline detection. This SNN will be utilized in coastline tracking applications using a UAV, and the collaboration represents a parallel effort towards advancing the development of efficient and effective vision-based systems. Overall, these research activities highlight the importance of hybrid approaches, neuromorphic computing, and visual servoing algorithms for the development of vision-based systems in UAV navigation and computer vision. The paper has been successfully accepted and presented at the conference convened in October 2023. Furthermore, during the months of November and December 2023, collaborative flights were executed in collaboration with partners from UNIWA and UL over beach locations. Initially focused on data collection for topographical and geomorphological analyses, these flights subsequently served the purpose of acquiring additional data to facilitate the development of an SNN-based algorithm for coastline detection.

ETHZ pursued the collaboration on neural netowk and energy efficient devlopyment in embedded platform with UCA. Moreover ETHZ put the majority of effort to have a fully working prototype around the Kraken SoC to have the first ever fully neruomorphic UAV.

IMSE has been able to properly bias the new 128x128 EF-DVS and mounted the lens and optics. The sensor has been demonstrated to work properly and correctly operates in high-resolution and low-resolution configurations. It is ready to be transferred to the other project partners. A visit from IMSE to NTUA or from NTUA to IMSE will be planned to transfer the technology and the know-how for setting up and using the EF-DVS sensor. IMSE is performing the extensive characterization of the optical and electrical characteristics of the sensor in different foveal configurations in their optoelectronics labs and a full paper publication is under preparation.

3.4. Technology readiness level (TRL)

Describe the global positioning of the project (from 'idea to application', or from 'lab to market'). Refer to Technology Readiness Levels (see definition here) at the beginning and at the end of the project.

In the beginning of the project, we were at TRL2 (technology concept formulated), and we reached TRL3 (experimental proof of concept) during Period 2. Due to an unexpected delay in the realisation of the demonstrator, the consortium is still working towards TRL4 (technology validated in lab) from Y3-Q3 (Fall 2022) to the end of period 3.
We expect to be able to finalise a simplified version of the demonstrator (UAV autonomously following a line on the ground by using neuromorphic sensors and processors) by the end of the project.

3.5. Consortium meetings

Provide the cumulative list of consortium meetings from project start.

Meetings during Period 1				
N°	**Date**	**Location**	**Attending partners**	**Purpose**
1	23/04/2020	Online	All	Kick-off meeting
2	16/09/2020	Online	All	Discussion about deliverables, agree on scenarios
3	06/11/2020	Online	All	WP0 and WP1 deliverables status update
4	17/12/2020	Online	All	WP work update, discussion about SpiNNaker
5	21/01/2021	Online	IMSE, UCA, INT, ETHZ	WP2: Technical specification for the foveal sensor
6	26/01/2021	Online	All	General plenary discussion, feedback after openAIRE workshop
7	03/02/2021	Online	UCA, UNIWA	Public website contents and administration
8	16/02/2021	Online	ETHZ, UCA, UL, IMSE, UNIWA, NTUA	WP4: Technical specifications for integration
9	18/03/2021	Online	All	Work synchronization, preparation of periodic report
10	30/03/2021	Online	All	WP1: Re-discuss scenarios and specifications, WP1 deliverables

Meetings during Period 2				
N°	**Date**	**Location**	**Attending partners**	**Purpose**
1	28/04/2021	Online	All	Feedback to the consortium after CHIST-ERA Project seminar, ongoing work, deliverables
2	10/06/2021	Online	All	Work synchronization
3	25/06/2021	Online	IMSE, UCA, INT, ETHZ	Technical DVS integration
4	06/07/2021	Online	All	WP5, neuromorphic stereo-matching
5	30/09/2021	Online	All	WP status and updates
6	01/11/2021	ETHZ	ETHZ, UCA	Work on neuromorphic visual attention on Loihi
7	23/11/2021	Online	All	Feedback after evaluation of Period 1, Exploitation, encourage transnational collaboration inside the consortium
8	20/01/2022	Online	All	Discussion about hardware platform and data

				format
9	15/03/2022	INT	INT, UCA	Work on motion detection, scene segmentation (1,5 day)
10	21/03/2022	Online	All	Extension request, organization of first physical meetings (mid-may at UCA, mid- July at NTUA)
11	30/03/2022	Online	NTUA, INT, UCA	Work on sea/shore classification for coastline tracking (several meetings in Y2-Q4)

Meetings during Period 3				
N°	Date	Location	Attending partners	Purpose
1	07/04/2022	Online	NTUA, INT, UCA	Continue the work on sea/shore classification for coastline tracking (several meetings in Y3-Q1)
2	19/04/2022	UCA	UCA, INT	Work on motion detection, scene segmentation (1,5 day)
3	24-25/05/2022	UCA	All	Physical meeting at UCA: technical discussion for all WP, tutorial for SpiNNaker
4	04/10/2022	Online	All	Work synchronization, on-going deliverables
5	08-09/11/2022	UNIWA / NTUA	All	Physical meeting at UNIWA / NTUA: Focus on efforts towards Milestone 3
6	23 to 25/11/2022	ETHZ	ETHZ, UCA	Work on visual attention: experiments on ETHZ neuromorphic chip, extension to multiple objects
7	28/02/2023	Online	All	On-going work, technical discussion about the demonstrator
8	14/04/2023	Online	All	Feedback after CHIST-ERA project seminar, focus on the demonstrator
9	12/06/2023	Online	All PIs	Executive committee meeting to discuss the funding situation of the Greek partners
10	04/07/2023	Online	All	Administrative updates, preparation of the final event, preparation of periodic report
11	14-15/09/2023	IMSE	All	Final project meeting + industrial session
12	07/12/2023	Online	All PIs	Executive committee meeting to discuss the finalization of the project (demonstrators, last reports)

3.6. Deliverables

Note that the contractual dates DO NOT take into account the 6-month extension request that the consortium will file before the project end.

Deliverables					
N°	Title	Nature	Delivery date (month)		Partner in charge
			Contractual	Actual	
D0.2.1	CA	Report	01/07/2020	20/01/2021	UCA
D0.2.2	RIMP	Report	01/07/2020	11/06/2020	UCA
D0.2.3	DMP	Report	01/10/2020	20/09/2021	UCA
D0.2.3	DMP Y2 update	Report	01/04/2022	02/09/2022	UCA

D0.2.3	**DMP Y4 (final)**	**Report**	**31/12/2023**	**20/12/2023**	**UCA**
D1.1	**Scenarios**	**Report**	**30/09/2020**	**31/03/2021**	**UL**
D1.2.1	**Specifications**	**Report**	**30/09/2020**	**31/03/2021**	**UL**
D1.2.2	**Specifications**	**Report**	**31/03/2021**	**30/09/2021**	**UL**
D2.1.1	**Fov. event cameras**	**Report**	**31/03/2022**	**22/05/2022**	**IMSE**
D2.1.2	**Fov. e-c tested**	**Syst./Rep.**	**30/09/2022**	**03/11/2022**	**IMSE**
D2.2.1	**Stereo system**	**Syst./Rep.**	**30/09/2021**	**31/03/2022**	**UCA**
D2.2.2	**Stereo fov. system**	**System**	**30/09/2022**	**30/09/2022**	**UCA**
D3.1	**SNN-ML for DVS**	**Report**	**30/09/2021**	**31/03/2022**	**INT**
D3.2	**Event depth**	**Report**	**30/09/2021**	**31/03/2022**	**UCA**
D3.3	**Fov. coast detec.**	**Report**	**30/09/2022**	**20/12/2023**	**UCA**
D4.1	**Digit/analog comp.**	**Report**	**30/09/2021**	**21/02/2023**	**ETHZ**
D4.2	**Soft/firm arch.**	**Report**	**31/03/2022**	**21/02/2023**	**UNIWA**
D4.3	**Working prototype**	**System**	**30/09/2022**	**20/12/2023**	**NTUA**
D5.1.1	**Visual servo. algo**	**Report**	**31/12/2021**	**07/06/2022**	**NTUA**
D5.1.2	**Motion interface**	**Report**	**30/09/2022**	**05/11/2022**	**NTUA**
D5.2	**Flight experiments**	**Syst./Rep.**	**30/09/2022**	**05/11/2022**	**NTUA**
D5.3	**System validation**	**System**	**31/12/2023**	**20/12/2023**	**NTUA**
D6.1.1	**Dissemination plan**	**Report**	**30/06/2020**	**11/06/2020**	**UNIWA**
D6.1.2	**Public website online**	**Website**	**30/09/2020**	**03/02/2021**	**UNIWA**
D6.1.3	**Dissem. report**	**Report**	**31/12/2023**	**20/12/2023**	**UNIWA**
D6.2.1	**Exploitation plan**	**Report**	**30/09/2021**	**31/03/2022**	**UNIWA**
D6.2.1	**Exploitation report**	**Report**	**31/12/2023**	**20/12/2023**	**UNIWA**

3.7. Free comments

Compliance with project objectives, interaction between the partners, issues, questions to CHIST-ERA...

Period 1:
The IMSE developments have not been published so far, as we are preparing a report for possible patent registration of the developments before submitting any result for publication.

Greek partners are in a difficult situation because of the funding access deadlock, that needs a special attention.

Period 2:
Most deliverables are delivered in time, either with the original timeline, or including a 6-month delay due to the pandemic (an extension request has been sent to CHIST-ERA). The consortium puts all efforts to stick to the original schedule and keeps delays within the 6-month extension.
IMSE has delayed the publication of scientific results regarding the new fabricated sensor due to the filing of a patent application and the lack of experimental results of the sensors.

Period 3:
The consortium has written the report for period 3 WITHOUT receiving feedback after the report of period 2. Some of the last deliverables are late due to the delay encountered in the project work in general, and especially in the demonstrator. This delay is mainly attributable to the serious financial difficulties faced by the Greek partners (long delay to access the budget, only a part of the budget could be spent).

4. Documentation of results, valorisation, impact

4.1. Scientific publications (conferences/workshops, book chapters, etc.)

Indicate the publications resulting from the project. Mention only those that result directly from the project (after it started, and which mention the support of CHIST-ERA and the project reference). Indicate whether they correspond to single or multi-partner communications (multi-partner means involving several project partners).

Distinguish the different categories of publications (journals/conference proceedings, technical reports, etc.). Use the usual citation standards for the field. If the publication is accessible on line, indicate the URL.

Please harmonise the bibliography and use only one font.

Scientific publications		
Publication Id	**Multi-partners (Yes/No)**	**International (Yes/No)**
Sotirios N. Aspragathos, George C. Karras and Kostas J. Kyriakopoulos, "A Visual Servoing Strategy for Coastline Tracking using an Unmanned Aerial Vehicle", submitted in IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS 2021), Sep 27 – Oct 1, Prague, Czech Republic	**No**	**Yes**
Amélie Gruel, J. Martinet. "Bio-inspired visual attention for silicon retinas based on spiking neural networks applied to pattern classification". Poster during the inauguration of Neuromod institute, 2021	**No**	**Yes**
Antoine Grimaldi, Victor Boutin, Laurent U. Perrinet, Sio-Hoi Ieng, Ryad Benosman. Event-driven Spiking Neural Networks for pattern recognition. COSYNE 2021	**No**	**Yes**
Amélie Gruel, Jean Martinet: Bio-inspired visual attention for silicon retinas based on spiking neural networks applied to pattern classification. Content-Based Multimedia Indexing (CBMI), Lille, France, 2021.	**No**	**Yes**
Amélie Gruel, Jean Martinet, Bernabé Linares-Barranco, and Teresa Serrano-Gotarredona. Stakes of foveation on event cameras. ORASIS 2021, Saint Ferréol, France	**Yes**	**No**
Amélie Gruel, Jean Martinet, Teresa Serrano-Gotarredona, and Bernabé Linares-Barranco. Event Data Downscaling for Embedded Computer Vision. International Conference on Computer Vision Theory and Applications (VISAPP 2022), Lisbonne, Portugal, Feb 2022	**Yes**	**Yes**
Amélie Gruel, Antonio Vitale, Jean Martinet, and Michele Magno. Neuromorphic Event-Based Spatio- temporal Attention using Adaptive Mechanisms. IEEE International Conference on Artificial Intelligence Circuits and Systems (AICAS 2022), Songdo Convensia, Corea, June 2022	**Yes**	**Yes**
Antoine Grimaldi, Victor Boutin, Laurent U. Perrinet, Sio-Hoi Ieng, Ryad Benosman. A homeostatic gain control to improve event-driven object recognition. Content-Based Multimedia Indexing (CBMI), Lille, France, 2021	**No**	**Yes**
Antoine Grimaldi, Victor Boutin, Sio-Hoi Ieng, Ryad Benosman, Laurent U. Perrinet. From event-based computations to a bio-plausible Spiking Neural Network. Champalimaud Research Symposium 2021	**No**	**Yes**
Antoine Grimaldi, Victor Boutin, Sio-Hoi Ieng, Ryad Benosman, Laurent U. Perrinet. A robust event-driven approach to always-on object recognition. TechRxiv 2021	**No**	**Yes**
Sotirios N. Aspragkathos, George C. Karras, Kostas J. Kyriakopoulos, "A Visual Servoing Strategy for Coastline Tracking using an Unmanned Aerial Vehicle", published in Mediterranean Conference on Control and Automation (MED 2022),	**No**	**Yes**

June 28 – July 1, 2022, Athens, Greece		
Sotirios N. Aspragkathos, George C. Karras, Kostas J. Kyriakopoulos, "An Event-triggered Visual Servoing Predictive Control Strategy for the Surveillance of Contour-based Areas using Multirotor Aerial Vehicles", published in IEEE/RSJ International Conference on Intelligent Robots and Systems, October 23-27 2022, Kyoto, Japan	No	Yes
Sotirios N. Aspragkathos, George C. Karras, Kostas J. Kyriakopoulos, "A Hybrid Model and Data-Driven Vision-Based Framework for the Detection, Tracking and Surveillance of Dynamic Coastlines Using a Multirotor UAV", published in MDPI Drones Special Issue "UAVs for Coastal Surveying"	No	Yes
Amélie Gruel, Dalia Hareb, Jean Martinet, Bernabé Linares-Barranco, Teresa Serrano-Gotarredona. Neuromorphic foveation applied to semantic segmentation. CVPR 2022 workshop "NeuroVision: What can computer vision learn from visual neuroscience?", New Orleans, Louisiana, June 2022	Yes	Yes
Antoine Grimaldi, Amélie Gruel, Camille Besnainou, Jean-Nicolas Jérémie, Jean Martinet and Laurent U. Perrinet. Precise Spiking Motifs in Neurobiological and Neuromorphic Data. Brain Sci. 2023, 13(1), 68; https://doi.org/10.3390/brainsci13010068. 2022	Yes	Yes
Amélie Gruel, Jean Martinet, Bernabé Linares-Barranco, Teresa Serrano-Gotarredona. Performance comparison of real time DVS data spatial downscaling methods using Spiking Neural Networks. WACV 2023, Hawaï, January 2023	Yes	Yes
Dalia Hareb, Jean Martinet. EvSegSNN : Segmentation sémantique neuromorphique pour la vision événementielle. ORASIS 2023, Carqueiranne, France. May 2023	No	No
Amélie Gruel, Jean Martinet. Sélection neuromorphique simultanée d'objets saillants dans des événements. ORASIS 2023, Carqueiranne, France. May 2023	No	No
Amélie Gruel, Lucia Trillo Carreras, Marina Bueno Garcia, Ewa Kupczyk, Jean Martinet. Frugal event data: how small is too small? A human performance assessment with shrinking data. CVPR 2023 Workshop on Event-based Vision, Vancouver, Canada. June 2023	No	Yes
Hugo Bulzomi, Marcel Schweiker, Amélie Gruel, Jean Martinet. End-to-end Neuromorphic Lip-reading. CVPR 2023 Workshop on Event-based Vision, Vancouver, Canada. June 2023	No	Yes
Amélie Gruel, Alfio di Mauro, Robin Hunziker, Luca Benini, Jean Martinet, Michele Magno. Embedded neuromorphic attention model leveraging a novel low-power heterogeneous platform. IEEE International Conference on Artificial Intelligence Circuits and Systems (AICAS 2023), Hangzhou, China. June 2023.	Yes	Yes
Amélie Gruel, Jean Martinet, Michele Magno. Simultaneous neuromorphic selection of multiple salient objects for event vision. IJCNN 2023, Queensland, Australia. June 2023.	Yes	Yes
Dalia Hareb, Jean Martinet. EvSegSNN: Neuromorphic Semantic Segmentation for Event Data. IJCNN 2023, Queensland, Australia. June 2023.	No	Yes
Amélie Gruel, Dalia Hareb, Antoine Grimaldi, Jean Martinet, Laurent Perrinet, Bernabé Linares-Barranco and Teresa Serrano-Gotarredona. Stakes of Neuromorphic Foveation: a promising future for embedded event cameras. Biological Cybernetics Special Issue: What can Computer Vision learn from Visual Neuroscience? 2023.	Yes	Yes
Sotirios N. Aspragkathos, Evangelos Ntouros, George C. Karras, B. Linares-Barranco, T. Serrano-Gotarredona, Kostas J. Kyriakopoulos. An Event-Based Tracking Control Framework for Multirotor Aerial Vehicles Using a Dynamic Vision Sensor and Neuromorphic Hardware. IEEE/RSJ International Conference	Yes	Yes

on Intelligent Robots and Systems, October 01-05 2023, Detroit, USA		
S. T. P. Gupta, P. Linares-Serrano, B. Sen Bhattacharya and T. Serrano-Gotarredona, "Foveal-pit inspired filtering of DVS spike response," *2021 55th Annual Conference on Information Sciences and Systems (CISS)*, Baltimore, MD, USA, 2021, pp. 1-6, doi: 10.1109/CISS50987.2021.9400245.	**No**	**Yes**
C. Chiplunkar *et al.*, "A Reduced-Scale Cortical Network with Izhikevich's Neurons on SpiNNaker," *2021 International Joint Conference on Neural Networks (IJCNN)*, Shenzhen, China, 2021, pp. 1-8, doi: 10.1109/IJCNN52387.2021.9534244.	**No**	**Yes**
T Serrano-Gotarredona, F Faramarzi, B Linares-Barranco, "Electronically foveated dynamic vision sensor," 2022 IEEE International Conference on Omni-layer Intelligent Systems (COINS)	**No**	**Yes**
T Serrano–Gotarredona, B Linares–Barranco, "System Architectures for Electronically Foveated Dynamic Vision Sensor," 2022 37th Conference on Design of Circuits and Integrated Circuits (DCIS)	**No**	**Yes**
I. Ortiz-Ramirez, L. Camuñas-Mesa, B. Linares-Barranco, and T. Serrano-Gotarredona, "Study of foveation mechanism in Dynamic Vision Sensors," 2023 Conference on Design of Circuits and Integrated Systems (DCIS'2023)	**No**	**Yes**

4.2. Valorisation (software, products, spin-offs, etc.)

Describe project spin-off effects, for example:

- *Software and any other prototype,*
- *Standardization actions,*
- *National and international patents, licences, and other elements of intellectual property,*
- *Launching of product or service, new project, contract, etc.,*
- *Development of a new partnership,*
- *Creation of a platform available to a community,*
- *Company creation, spin-off companies, fund-raising.*

Period 1:
UCA participates in the new French ANR-funded DeepSee project, that focuses on the use of SNN for the intelligence of embedded systems, with an automotive application.

For INT, during this period, we started the ANR AgileNeuroBot project in synergy with the APROVIS3D project. The aim of the AgileNeuroBot project is similarly to develop an end-to-end event-driven approach, yet for building an ultra-fast motor controller for object avoidance.

ETH had access to the INRC community from Intel and now ETH can work with the Intel Loihi processor. The platform will be benchmarked and eventually used in the project for benchmarking and comparison purposes.

(IMSE: Nano-Mind- http://www2.imse-cnm.csic.es/nanomind/ National project in cooperation with Univ of Valencia and Univ of Seville)
(IMSE **Memory technologies with multi-scale time constants for neuromorphic architectures (MeM-Scales)** H2020-ICT-2019-2-871371. January 2020-December 2022
(IMSE Weighted Spintronic-Nano-Oscillator-based Neuromorphic Computing System Assisted by laser for Cognitive Computing (Spinage) H2020-FETOPEN-2020-01-899559. October 2020- September 2024)

Period 2:
IMSE Patent: T. Serrano-Gotarredona and B. Linares-Barranco, 'Electronically Foveated Dynamic Vision Sensor', ES1641.1671 . Filling date October 5th 2021, CSIC (90%) and Universidad de Sevilla (10%).

(IMSE Two-Dimensional Oscillatory Neural Networks for Energy Efficient Neuromorphic Computing (NeurONN) H2020-ICT-2019-2-871501. January 2020-December 2022)
(IMSE ULTRA-ENERGY EFFICIENT AND SECURE NEUROMORPHIC SENSING AND PROCESSING AT THE ENDPOINT (NimbleAI) HORIZON-CL4-2021-DIGITAL-EMERGING-01-01)
(IMSE Distributed and federated cross-modality actuation through advanced nanomaterials and neuromorphic learning (Crossbrain) HORIZON-EIC-2021-PATHFINDERCHALLENGES-01-02)

Period 3:
The project final event took place at IMSE on September 14-15, 2023. The consortium has organised an industrial session with several companies (Inivation, Sony, Yumain, IMRA Europe, Renault Software labs, Synsense, Ucandrone) that came for two online sessions: one session where the companies have been offered the opportunity to pitch their products, and one session where the consortium did advertise the main project results to the companies. This session was a success for all.

UCA will be the coordinator of the upcoming ANR-funded project NAMED (Neuromorphic Attention Models for Event Data) from 01/02/2024 for 48 months.

IMSE has established collaborations with Prof. Bhattacharya (BITS Pilani University, Goa, India) in studying biological modelling of the processing of the foveal dynamic vision sensor recordings in the cortical regions. Several publications have resulted from this collaboration.

4.3. Other dissemination of results

Mention any communication actions, including the project website creation and management.

Period 1:
In WP6, UNIWA has designed and opened a public website for the project http://www.aprovis3d.eu. UNIWA administrates the websites, and UNIWA and UCA update the contents.

INT : https ://laurentperrinet.github.io/grant/aprovis-3-d/

UCA and INT post from time to time on Twitter to advertise the project's achievements.

UCA released on March 31, 2021, a short video advertising the project for the CHIST-ERA video contest.

UCA: Invited talk during the Technical Workshop on Integrated machine-learning hardware for near-sensor computing applications, organized by CHIST-ERA JEDAI project.

UCA advertised the project to the local CNRS-UCA GéoAzur lab (telluric hazards, lithosphere deformation), which coordinates an ongoing IRD project with Luxcarta (Sophia Antipolis, expert in geodata, geospatial products, RF 3D maps of landscapes, cities), and CNRS-CNES-IRD Legos lab (Toulouse. Expert in geophysics, costal oceanography). They are interested in deep learning for recognition and extraction of topographic 3D features (such as coastline, hydrographic network, dams, buildings, roads, sand dune ridges, sedimentary and geological boundaries). This project may be a future opportynity to publicize / disseminate APROVIS3D project results.

Period 2:
UCA: Organization of interactive local conference "Mind Yourself! How does computer science interact with neuro- sciences?" during the Brain week 2022 at UCA by A. Gruel at Learning Centre SophiaTech (approx. 40 participants).
IMSE: http://www2.imse-cnm.csic.es/neuromorphs/index.php/Projects, organization of a special session on Bio-inspired circuits, systems and algorithms for multimedia during CBMI'2021, Lille, France.
UNIWA advertises the project in the 3rd educational visit (14-17 March 2022 in Athens) of Erasmus+ project, GeoDRR (Geomatics for Disaster Risk Reduction) by spreading out dissemination results to gain attention from future PhD candidates in the subject of automated coastline detection for risk reduction.

Period 3:
Whole consortium: industry session during the final project meeting in September 2023.
IMSE: Lecture on Sustainable Hardware in Summer School AI-HUB CSIC 2022, Palma de Mallorca, 4 July 2022. IMSE PI has participated in an industry panel entitled "Ethics and Sustainability in the Digital Era" with a short video and presentation "Neuromorphic Systems for a sustainable artificial intelligence". The panel took place in CSIC Science House, Sevilla, October 30th 2023.

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5. Resources and Funding

5.1. Project level (from project start)

Budget used in Period 1				
N°	**Partner**	**Person.months**	**Total costs**	**Percentage of requested budget**
1	UCA	6 (PhD student)	19.5 k€	13.07%
2	UL	0	0	0%
3	INT	6 (PhD student)	30.99 k€	20.66%
4	IMSE	4 (PhD student)	11.45 k€	7.6%
5	UNIWA	0	0	0%
6	NTUA	0	0	0%
7	ETHZ	12 (PhD student)	50.5 k€	30%

Budget used in Periods 1 and 2				
N°	**Partner**	**Person.months**	**Total costs**	**Percentage of requested budget**
1	UCA	18 (PhD student)	58.5 k€	40.5%
2	UL	1 (Research engineer)	3 k€	5 %
3	INT	18 (PhD student)	61.25 k€	50 %
4	IMSE	16 (9 PhD student, 7 higher degree contract)	79.2 k€	52,9%
5	UNIWA	2,23 staff + 9,1 PhD student	32.08 k€	32.08%
6	NTUA	2.24 (PhD student)	33.44 k€	33.46%
7	ETHZ	24 (PhD Student)	109 k€	60%

Budget used in Periods 1, 2, and 3				
N°	**Partner**	**Person.months**	**Total costs**	**Percentage of requested budget**
1	UCA	36 (PhD student)	132 k€	100%
2	UL	12 (Research engineer)	48.83 k€	83.5%
3	INT	36 (PhD student)	148.5 k€	100%
4	IMSE	28 (9 PhD student, 19 higher degree contract)	149.7 k€	100%
5	UNIWA	12 (PhD student)	52.16 k€	52.16%
6	NTUA	4 (PhD student) + 8 (staff)	69.86 k€	69.92%
7	ETHZ	36 (PhD Student)	179.1 k€	100%

Comments on expenses

Period 1:
At UCA, the main budget used is for hiring a PhD student (Amélie Gruel) from 01/10/2020. No kick-off cost, no travel cost, no publication fees, no investment yet.
At UL, no budget has been used yet. A recruitment of engineer is planned for end of Y2.
At INT, main budget used: hired a PhD student (Antoine Grimaldi) from 01/10/2020 and a master student (6 months, from 04/01/2021 to 31/05/2021, salary of 2847€). Computer with 32 cores and GPU bought in march 2021 (5k€) and laptop in January 2021 (2k€).
At IMSE, main budget used has been for hiring a PhD student (Farnaz Faramarzi) for 26/11/2020 (8,76k€). Two laptops for chip design and lab testing have been acquired (2,6K€).

At UNWA and NTUA, no funding was received during the entire first year.
At ETHZ, the budget use for hiring a PhD student.

Period 2:
At UCA, the main budget used is for the PhD student (A. Gruel), and some travel expenses to conferences (CBMI, ORASIS, VISAPP).
UL has recruited an engineer starting 1st March 2022. This is the sole consumption of the recieved budget from the funding agency, roughly 3 k€ (but will continue in the 3rd period). This engineer works with the other partners on the design and implementation of the spiking neural network for the coastline detection.
At INT, the main budget that was used is for the cost of participations at conference for the PhD student (A. Grimaldi), virtual (COSYNE, CBMI) or in presential (CRS, Lisbon).
At IMSE, main budget used has been for hiring 9 months a PhD student (Farnaz Faramarzi) for 26/11/2020 to September 2021 (19,7€) and a higher degree contract (Ivan Díez de los Ríos) from September 2021 until now (20K). Other important cost has been the fabrication of the 128x128 sensor in the AMS 0,35micron OPTO technology (26K). Other costs in the period: travel costs (8k), and PCB fabrication and components (4K).
The UNIWA budget was used for staff costs, consumables, and equipment update. Personnel cost include a PhD student (8147,50€) and permanent staff (11771,87€). Other costs regarding consumables and equipment include the updating of a prototyping machine for PCB assembly and consumables for production (9669,64€), PC /printer for topographic/coastline calculations (2492,42€).
At ETHZ, the budget use mainly for the PhD student salary.

Period 3:
At UCA, the main budget is used for the PhD student and for the travel expenses to go to conferences / registration (CVPRw, WACV, AICAS, JOBIM, ICIP, IJCNN, etc.), and host/go to project physical meetings. Some hardware was acquired in the final period to finalize the demonstrator (commercial UAV for training data acquisition, laptop to host the 3D ground demonstrator).
UL has spent 49 832.03€ out of the allocated 59 670€ (49 213.15 as human resources (Mazdak Fatahi as engineer) and 618.88 as travel expenses). This represents 83.5 %.
At INT, the remaining budget was used to pay the salary for the hired PhD student to the 30/09/2023 and for travel expenses related to the project (meeting at IMSE, Capo Caccia summer school).
At IMSE, main budget used has been for hiring a higher degree contract (Ivan Díez de los Ríos) from March 2022 until now (33.5k). Other important cost has been the fabrication of the new vision sensor (24K) in the XFAB0.18 technology. Other costs: travel cost and host/go to project meetings (3.5k), consumables (6.4k).
At ETHZ, most budget has been spent on funding the PhD student.
The NTUA budget was used for staff costs (21420,69€) + 1 PhD student (12000,00€) and for the travel expenses to go to conferences / project physical meeting (5283,99€).