WHITE PAPER

Concurrent AI image processing in Space using Klepsydra software running on 16-cores LX2160-Space processor from Teledyne e2v.

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ABSTRACT

Performing on-board data processing in the spacecrafts typically requires large amount of computing capabilities to handle the large data rates that the edge computing applications require. These applications can be for instance image processing for Earth observation, automated landing, and on-board decision making for debris avoidance. More and more of these applications are relying on Artificial Intelligence rather than traditional computing to analyze the data and make decisions. Because of the high processing requirements and the specificities of executing AI, it is not only a question of using the fastest processors, but also of optimizing the resource utilization when computing the neural networks. Another requirement that comes on top of the pure computing performance is the capability to operate multiple tasks (i.e. neural networks) in parallel to manage several functions and possibly serve several users. This is served both by multicore processors to split the tasks among different cores, and by implementing the software in a smart way to share efficiently the resources (CPU usage, memory, ...).

Klepsydra is a Swiss SME focusing on developing high-performance edge data processing software for autonomous embedded systems to serve applications in the Space, aerospace, smart mobility and IoT industries. Klepsydra will provide the high-performance SW framework that allows to perform the necessary computing and AI/ML tasks on the available on-board computer.

Teledyne e2v offers Space-grade digital components, including processors, memories, and processing modules, to support the Edge computing in Space. The LX2160-Space is a latest-generation Radiation-Tolerant processor featuring 16-cores ARM® Cortex®-A72, that offers a disruptive computing capability of 200,000 DMIPs / 280 GFLOPs, together with a large number of high-speed interfaces such as PCIe Gen3.0 and up to 100 Gb Ethernet to interface with other subsystems. These features make the LX2160-Space an ideal candidate for performing multiple AI tasks in flight, and to be the "brain" of the spacecraft.

This white paper discusses the implementation of concurrent AI image processing using Klepsydra software running on the Teledyne e2v LX2160-Space processor. First, the general AI as a Service (AIaaS) approach is presented. Then, the scenario taken for the case study is described, including the details on the neural networks. Finally, the performance key results are presented.

II. AI AS A SERVICE (AIAAS) APPROACH

The combination of LX2160-Space and Klepsydra framework demonstrates a unique application scenario within the Satellite-as-a-Service paradigm. With AI-as-a-Service (AIaaS), customers can easily benefit from the novel concept to implement artificial intelligence capabilities on satellites and combine it with a shared service approach. AIaaS offers a new way to deploy artificial intelligence in Space. Customers do not need to build, own, maintain or upgrade their own Space infrastructure nor do they require specific software development skills to implement AI-in-Space, since AIaaS covers all of this. The unique element of the proposed AIaaS is the fact that a customer ONLY needs to provide a ML model and execute it.

With this concept, several independent AI algorithms are executed and run in parallel on the processor, allowing multiple customers to use this common resource in Space for executing their AI models. The proposed AIaaS on-board of a satellite is leveraging the Klepsydra software framework in a unique way. It allows customers to focus on providing the AI/ML Model while the execution engine is available as a service on-board of the satellite. Thanks to this, the customer is not exposed to the needs of working with the SW framework, since this is already compiled and installed on the Space computer. All the customer needs to do, is to provide an ML Model in line with the technical requirements. Then, the model will be uploaded onto the Space computer and will be executed for the contractually agreed time. In addition to the ease-of-use, customers leverage the computational performance of the Klepsydra SW framework without the time and money needed to reach this performance.

Based on the Klepsydra SW framework and multicore processors from Teledyne e2v, AIaaS ensures a very efficient performance of the AI models on the satellite. The Klepsydra framework increases the available computational power for the execution of AI in Space. The Klepsydra AIaaS solution offers superior processing performance and thus enable customers to run AI in Space at full throttle. To summarize, the AI-as-a-Service brings the following benefits:

- Efficient use of existing Space hardware
- Easy validation of new applications in Space
- Allow an iterate fast, fail-fast approach on new applications
- Provide first service offerings without major investments
- Further lower the barrier of entry for AI/ML based business model and science
- New business model based on shared resources

III. SCENARIO FOR THE CASE STUDY

In the following case study, the concept is presented in action. Three independent AI algorithms are executed and run in parallel on the powerful LX2160-Space processor. The AI use cases selected as examples for the case study are described in the following sections.

a. Onboard Geolocalization with Image Sensors

Geolocation on Earth Observation satellites is a process that determines the precise location of a target on Earth using data from sensors onboard the satellite. It is used for various applications like mapping, monitoring natural disasters, tracking climate change, and assisting in defense operations. The accuracy of geolocation can vary based on the sensor used, image resolution, and processing algorithms. In this example, the KAMnet Deep Neural Network (DNN) is used to perform AI based geo-location. KAMnet is a DNN designed for geolocalization using images as input data.

It can accurately determine the geographic location of an image by learning the non-linear transformation from the image's 2-Dimensional space to the geolocation's 3-Dimensional space. An example of execution is shown on Figure 1, where the difference between real and estimated positions are compared.

In the practical implementation, the neural network takes 224x224 grayscale images from a 1000km^2 area and provides an estimated latitude and longitude of the image center. The network used is a Convolutional Neural Network (CNN) with sequential regression. It has 7 layers organized as follows:

- 2 Convolutional layers with ReLU activation
- 2 Maxpool layers
- 3 Gemm layers

For this task, 4 cores of the LX2160-Space are allocated to perform the inference, and 2 additional cores are used for map rendering to display the results. A ZMQ communication transfers data from the network to the map rendering engine.

Figure 1 : Example of geolocalization based on image sensors.

b. Onboard Cloud Detection in Images

Cloud detection is a crucial process in Earth Observation used to identify and mask clouds in satellite imagery. This is necessary because clouds can obstruct the view of the Earth's surface, making it difficult to accurately interpret and analyse the data or waste bandwidth by downloading "useless" images. The cloud detection AI algorithm used in this case study was developed by the Barcelona Supercomputing Center and ESA. This algorithm uses segmentation for cloud detection on an open-source dataset called Cloud95. U-Nets have become a standard approach for segmentation tasks and have also been shown to be effective on cloud screening tasks. However, there are constraints for using U-Nets in on-board processing, such as the enormous amount of parameters and high computational cost. In the final implementation, a good balance between computational complexity/memory footprint and prediction accuracy was selected. Figure 2 presents an example of the cloud detection as implemented, where a grayscale map of the cloud coverage is constructed.

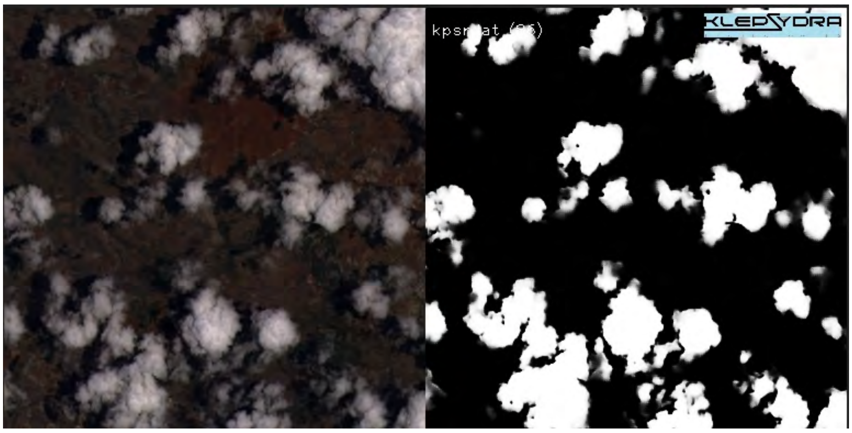

Figure 2 : Example of cloud detection.

The DNN takes 384x384 4-channel images (Red, Green, Blue, and Near Infrared) as input. Each channel ('color') is stored separately on the disk, hence there is a first preprocessing step which merges all 4 images into a single one, before feeding the network. The network then generates a 384 x 384 grayscale image mask, where white corresponds to cloud cover and black corresponds to areas without clouds. The test dataset was prepared from Landsat 8 scene images and their manually extracted pixel-level ground truths for cloud detection. The entire images of these scenes were cropped into multiple 384*384 patches. The network has UNet architecture with 31 main layers implemented on 4 cores of the LX2160-Space:

- 18 Convolution layers with Rectified Linear Unit (ReLU) activation
- 4 Transposed Convolution layers
- 4 Maxpool, 4 Gemm, and 1 Sigmoid layers

c. Coronal Mass Ejection Detection

A coronal mass ejection (CME) is a significant release of plasma and accompanying magnetic field from the Sun's corona into the heliosphere. In the context of Space Situational Awareness (SSA), on-board detection of Space weather events – such as solar flares or Coronal Mass Ejections (CME) – can decrease the system latency for critical information reaching the end-users. ESA has developed and optimized two machine learning applications based on ANN (Artificial Neural Networks) targeting Space weather applications: on-board coronal mass ejection detection and detection of radiation upsets in optical imagers for on-board radiation scrubbing. In the case study, the coronal mass ejection detection application is implemented, which estimates a probability of occurrence, as shown on Figure 3.

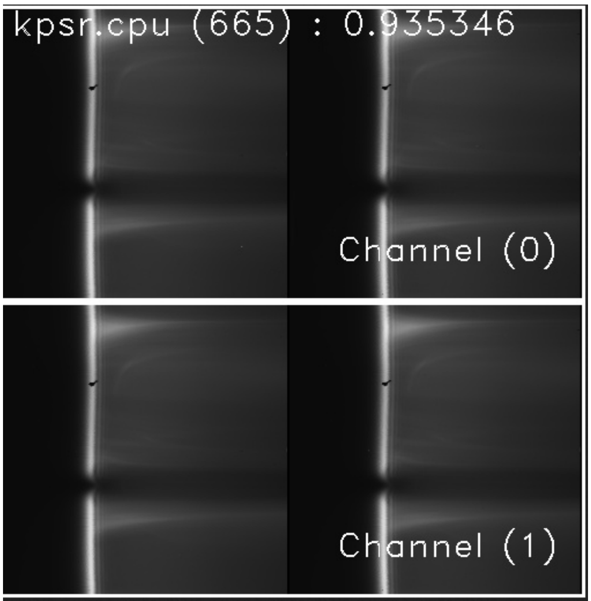

Figure 3 : Example of coronal mass ejection detection.

The coronal mass ejection detection is fitted on 4 of the remaining cores of the LX2160-Space. It takes 2 grayscale images of 512x1024 as input and provides a probability that mass ejection is occurring. The data is stored in HDF5 format, and preprocessing includes parsing the HDF5 file before converting to image. The neural network is a CNN based sequential classification network with 6 layers:

- 4 Convolution layers
- 1 Gemm and 1 Sigmoid layers

IV. IMPLEMENTATION AND PERFORMANCE

The proposed scenario was implemented on a development board featuring the LX2160-Space to verify the performance in practice on the real target. The LX2160-Space was operating at a frequency 2GHz, and was companioned with 16GB of DDR4 with speed of 2666MT/s. The Klepsydra software was loaded and executed, the Table 1 provides a summary of the test case, resources allocated, and the performance obtained:

Table 1 : Summary of the AI algorithms performance with Klepsdyra software on LX2160-Space.

	Geolocalization	Cloud detection	Coronal mass ejection detection
Neural Network type	CNN based sequential regression network - 7 layers: • 2 Convolution layers • 2 Maxpool layers • 3 Gemm layers	UNet architecture - 31 layers: • 18 Convolution layers • 4 Transposed Convolution Layers • 4 Maxpool, 4 Gemm, 1 Sigmoid	CNN based sequential classification network - 6 Layers: • 4 Convolution layers • 1 Gemm layer • 1 Sigmoid layer
Size of the Network	117MB	17MB	370kB
Input	224x224 grayscale images	384x384 RGB + near-IR images	512x1024 2-channel grayscale images
Output	Estimated latitude and longitude	384 x 384 grayscale cloud coverage image	Probability of mass ejection
Resources allocated	4 cores for the network 2 cores for map rendering engine	4 cores for the network	4 cores for the network
Processing rate	**2Hz (500ms image processing time)**	**0.5Hz (2s image processing time)**	**12.5Hz (80ms processing time)**

Thanks to the combination of Klepsydra software framework and LX2160-Space processor from Teledyne e2v, concurrent AI image processing can be performed in Space. The performance is very good considering the complexity of the two first DNN (geolocalization and cloud detection) which are very heavy. As expected, coronal mass ejection detection is running faster due to its lower size.

V. SUMMARY

This white paper presented the AI as a Service (AIaaS) concept combining Klepsydra framework with Space qualified multicore processors from Teledyne e2v. A case study was realized on LX2160-Space processor to perform AI processing in parallel to target several applications. The case study demonstrated the Klepsydra AI software and Teledyne e2v processor's remarkable capacity to concurrently execute multiple AI algorithms. The focus was made on the case of high-performance image processing for Earth Observation applications, and the approach could be transposed to other applications.

This system supports the Satellite as a Service paradigm, facilitating the shared utilization of satellite onboard processing resources among diverse users seeking distinct information from the same imaging sensor data.

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