Campagne 2020 Contrats Doctoraux Instituts/Initiatives

Proposition de Projet de Recherche Doctoral (PRD)

Appel à projet IPhyInf - Initiative Physique des infinis 2020

Intitulé du Projet de Recherche Doctoral : Meteor-RT: Design of a real-time computer vision application embbeded within a satellite for meteors and debris detection

Directeur de Thèse porteur du projet (titulaire d'une HDR) :

NOM : **LACASSAGNE** Prénom : **Lionel**
Titre : Professeur des Universités ou

e-mail : lionel.lacassagne@lip6.fr
Adresse professionnelle : Sorbonne Université - Campus Jussieu, 4 place Jussieu, 75252 Cedex 05
(site, adresse, bât., bureau)

Unité de Recherche :
Intitulé : LIP6
Code *(ex. UMR xxxx)* : UMR 7606

Ecole Doctorale de rattachement de l'équipe & d'inscription du doctorant : **ED130-EDITE**

Doctorants actuellement encadrés par le directeur de thèse (préciser le nombre de doctorants, leur année de 1ere inscription et la quotité d'encadrement) : 3

Thomas Romera 2019 (CIFRE, 50%)

Arthur Hennequin 2019 (CERN, 50%)

Ilias Bournias (Europe, 50%)

Co-encadrant :

NOM : **VAUBAILLON** Prénom : **Jérémie**

Titre : Maître de Conférences des Université ou Assistant astronome HDR ☒
e-mail : Jeremie.Vaubaillon@obspm.fr

Unité de Recherche :
Intitulé : IMCCE
Code *(ex. UMR xxxx)* : UMR 8028

Ecole Doctorale de rattachement : **ED127-AstronomieAstrophysiqueIdF**
Ou si ED non Alliance SU :

Doctorants actuellement encadrés par le co-directeur de thèse (préciser le nombre de doctorants, leur année de 1ere inscription et la quotité d'encadrement) : 2

Esther Drolshagen 2017 (Univ Oldenburg, 30%)

Theresa Ott 2017 (Univ Oldenburg, 30%)

Cotutelle internationale : ☒ Non ☐ Oui, précisez Pays et Université :

Description du projet de recherche doctoral *(en français ou en anglais)*

3 pages maximum – interligne simple – Ce texte sera diffusé en ligne

Détailler le contexte, l'objectif scientifique, la justification de l'approche scientifique ainsi que l'adéquation à l'initiative/l'Institut.
Le cas échéant, préciser le rôle de chaque encadrant ainsi que les compétences scientifiques apportées. Indiquer les publications/productions des encadrants en lien avec le projet.
Préciser le profil d'étudiant(e) recherché.

Introduction

If designing a nano-satellite is a real challenge, the Meteorix project is even more challenging. Today more than two thousands of nano-satellites have been launched or are under design [http://www.nanosats.eu], but very few embed computer vision and image processing on board. The few to do so only acquire images and then retransmit them without processing (except compression) to a ground station. Until recently, no nano-satellite had the ambition to embed high performance computing on board to directly process the images. Today the only existing project to propose such a mission is Meteorix from Sorbonne University. The processing chain embedded on the nano-satelitte Meteorix aims to detect events of type "meteor and debris" from the images acquired on-board.

Today, the vast majority of space systems communicate with the Earth to download the data to be processed and to receive orders. This implies proximity with Earth (to have an acceptable latency) and a powerful and energy-consuming antenna (for a fast transmission that is adapted to the quantity of data).

In the future, spacecraft will have to be more and more autonomous with more decision-making on-board, to be able to carry out ever more complex missions where the capacities of adaptation and intelligence will be essential. Several reasons for this: the distance from Earth will be incompatible for an accurate mission control (latency and reactivity) or the need for an ever-greater bandwidth to download interesting data and upload actions. There will be more and more computation to be done on board and to integrate in small systems to limit the impacts at the system level (mass, power consumption, …). The size of these systems will engender power consumption constraints that will result in the need to optimize the codes to embed.

As a comparison of the evolution of computing power, the first generations of Martian rovers like Mars Pathfinder (1997) and Spirit / Opportunity (2003- ...) were embedding a RAD6000 processor (the hardened version of the PowerPC 601) running at 20 MHz and with a computing power of 20 Mips (Million instructions per second). The latest generation of rover (Curiosity 2012-...)) embeds two processors RAD750 (the hardened version of PowerPC 750) at 200 MHz for a computing power of 400 Mips. Today, the most powerful processor in this family is the RAD5545 (quad-core version of the PowerPC e5500). It is especially the first version to implement an SIMD unit (Altivec) for a computing power of 5600 Mflops (million of floating operations per second). A first study carried out as part of the Meteorix Preliminary Requirements Review has highlighted the need for this type of SIMD multi-core processor while limiting the power consumption of a few watts.

PhD Thesis

This thesis aims to study the high-performance embedded parallel architectures (CPU and FPGA) - current and future - from a point of view of computing power, but also of consumption (power and energy) to draw roadmaps on the feasibility of typical missions. These roadmaps will be established according to the consumption constraints that will limit the available computing power (typically of the order of a few watts for the Meteorix satellite). The research plan of the thesis is initially composed of three steps.

Step 1 - Initial version. This first step aims at the development of a complete processing chain that will provide a first configuration in terms of speed and detection quality:

- Develop a complete computer vision application (based on optical flow and segmentation) as well as the associated test bench for a qualitative validation of the image sequences (labeled in order to have a ground truth) acquired from the Meteor camera onboard the ISS.

- Optimize the algorithms for low-power multi-core SIMD processors (ARM Cortex Neon for spatialized boards like Ninano from steel-electronique : Zynq 7030 + dual ARM Cortex A9 SIMD) and high-performance boards combining multi-core SIMD processor + GPU (Nvidia Jetson board TX2, AGX, Nano).

Step 2 - auto-adaptable version based on a statistical approach:

- Extract and build statistical information (average and standard deviation of circular statistics) from optical flow to get a robust detection algorithm (the apparent speed of Earth cities viewed from ISS varies and depends on the observed scene cloud, aggregation of lights, …). This will make the application insensitive to focal lens, exposure time, sensor size, altitude, frame rate.

- Qualify the application with all existing video from ISS-Chiba experiment.

Step 3 - Iterative improvement according to three antagonistic constraints of computer vision application:

- Algorithmic optimization of the computer vision and image processing operators to accelerate them in order to reach the real time (25 frames per second) while enforcing the qualitative aspect.

- Sustain a detection threshold (via parameters calculated on ROC matrices)

- Optimization of calculation formats (floating-point and fixed-point calculation to maximize parallelism while minimizing the memory footprint (compared to the original 32-bit floating point format) to provide additional acceleration.

- Measurement of energy consumption.

Objectives and results: This thesis must provide different configurations of the computer vision application to achieve trade-offs in terms of speed / quality of detection / power consumption in order to target several embedded parallel architectures identified by their computing power and their consumption (for example 2 W, 5 W, 10 W, 20W). A proof-of concept of a low power configuration has already been published (COMPAS 2018, COSPAR 2018, DASIP 2018, ESA 2019). The finalized low power configuration should be embedded in the in the nano satellite Meteorix while a high-performance configuration could be used in a more power full satellite.

Designing algorithms and developing codes for Meteorix is not the ultimate goal - even if it remains a challenge (there is no launched nano-satellite with such a mission) - but will serve as a test. The objective is to capitalize software and architectural bricks of embedded computation and the expertise acquired on the Meteorix project for future projects. Like the SPOT family of satellites and its chain of image acquisition and compression, it is reasonable to consider that these bricks can be used and reused in other satellites or other spacecraft where the movement needs to be addressed (phenomena to be detected and tracked, autonomous robotic navigation, ...), in order to simplify and improve the performance of future space projects - while controlling their costs and impacts at the system level.

Currently the TRL level is 3 (proof of concept). A reasonable TRL level for the end of this thesis will be 5 ("environmental verification representative of the critical function at the component level and / or model - scale models") or 6 ("Demonstration in an environment representative of the critical functions of the element at the model level - design validation").

The materials cost for such a demonstration will be borne by the space campus, Universities, associated UFRs and laboratories. They will be low because it will be the non-spatialized versions of the components (COTS) that will be used whenever possible. Thus it was possible to test ARM CPUs A7, A15, A53, A57 as well as GPU TK1, TX1 and TX2.

Financial support: the company ACRI-ST is interested and supports the project

Profile: student in computer science and electronic engineering who has taken courses in computer architecture and high-performance computing and knowing at least one of the target architectures (multi-core processors SIMD or FPGA). Knowledge in signal processing, image processing or computer vision will be a plus. Motivation and the desire to take on challenges are necessary.

Doctoral School : EDITE (http://edite-de-paris.fr)

Contacts:

- Lionel Lacassagne, Professor in computer architecture at LIP6, Sorbonne University, head of ALSOC team (architectures and software for systems on chip), PI computer vision and code optimization & parallelization of Meteorix, lionel.lacassagne@lip6.fr http://www-soc.lip6.fr/~lacas/

- Jérémie Vaubaillon, Associate Professor in Astronomy and Astrophysics at IMCCE, scientific PI meteor and camera of Meteorix mission, jeremie.vaubaillon@osbpm.fr

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cd_instituts_et_initiatives@listes.upmc.fr avant le 30 mars.