Postdoctoral proposal KIM 2021

DeepHornetMonitoring

Measuring the impact of the Asian hornet in the apiary by deep-learning applied to video surveillance: towards an automated information system for pollination resources

Keywords: Asian hornet, invasive species, bee decline, digital agriculture, deep learning, insect tracking, video surveillance, big data analysis, artificial intelligence

Context and issues

The Asian hornet, an important predator of pollinating insects, was accidentally introduced in France in 2004 and quickly became an invasive species in Europe [1]. Its favourite target is the honeybee, a key biodiversity link and the main pollinator of many food crops. By hovering in front of hives, this hornet contributes to the bee colony collapse syndrome [2], in addition to pesticides, parasites and climate change [3]. The Asian hornet thus hinders bee pollination services, thereby threatening not only biodiversity, but also agriculture and human food security [4]. Research to control the Asian hornet is increasing but it is mainly focused on the development of bee muzzles [5], traps and/or baits [6,7]. Its behaviour and flight dynamics (as well as the biotic and abiotic parameters likely to influence them) remain little studied even though they are at the heart of its predation success [8]. Furthermore, its direct impact on hives in terms of bee predation is assessed by rough and time-consuming estimates, as they are based on laborious counts of predation events, which are not immune to error [8]. Its indirect impact in terms of foraging paralysis of bees can be assessed by simulation modelling [9]. But these models do not make it possible to warn in real time about the threshold, in terms of hornet number, which endangers the supply of nectar and pollen to the hives and thus the colony survival. Sixteen years after the introduction of the Asian hornet in France, it is therefore necessary to develop a reliable and automated methodology to detect and count hornets, foraging bees and predation events at the entrance of hives in order to quantify the impact of the hornet on apiaries and to analyse its evolution over time. The automatic processing of mass data acquired across the country would allow an accurate assessment of the economic cost of this predator. It would also make it possible to know the types of apiaries most affected and to alert on the timing and conditions favourable for intervention or trapping, as well as to evaluate the effectiveness of the traps developed.

Problematic

A two-fold problematic

This project addresses, on the one hand, one of the major challenges of Sustainable Agriculture concerning the perpetuation of the pollination capacities of bees essential to agricultural production, and on the other hand, a challenge of artificial intelligence, which is the development of digital tools to process video mass data of insect behaviour.

(1) The applied (agro-)ecological project aims at assessing the daily predation rate of honey bees by the Asian hornet in a small apiary (installed at CIRAD in the framework of the MUSE CarniVespa 2017-2021 project [1] dedicated to the development of a bioinspired trap against the hornet). From 2016 to 2019, the hives were equipped with low-definition, low-frequency cameras; films were taken continuously one day a week for 4 months from July to November from 2016 to 2018 totalling more than 360 hours of acquisition, i.e. 32 million frames. The aim of the project is to study the behaviour of hornets and to count, in an automated way, from the video surveillance data on the hives, the bee capture/ bee attack ratio over time and to test whether the predation rate of the bees varies according to the year, season, time of day, weather conditions, physical protection or traps installed around the hives (muzzle, beak trap, CarniVespa trap, etc.).

(2) Detecting and automating the counting of Asian hornet attacks on the honeybee on video images raises questions of artificial intelligence and deep-learning applied to moving objects. To meet these objectives, it is necessary to train deep neural networks and test their capacity to detect and track the Asian hornet on videos, i.e. in time and space. Encouraging preliminary

results were obtained in 2020 on this subject thanks to a Master 2 computer science internship financed by the I-Site MUSE [10] (AAP-M2_KIM-Data&LifeScience 2019). Neural networks have proved capable of detecting different categories of insects (foraging bees/Asian hornets/hornets having captured a bee) on video images thanks to the YoloV4 detector (Fig. 1) but their tracking by the V-OUI tracker in space and time has proved more problematic, mainly because of the too low acquisition speeds of the cameras (Fig. 2). In the autumn of 2020, the initial devices were therefore replaced by ultra high definition and high frequency Go Pro Hero9 cameras producing from 100,000 to 800,000 frames per hour.

Figure 1: Object detection by the CNN YoloV4. Bees grouping together to protect the entrance to the hive; detection of foraging bees in blue, hornets in orange, and bee captures in red.

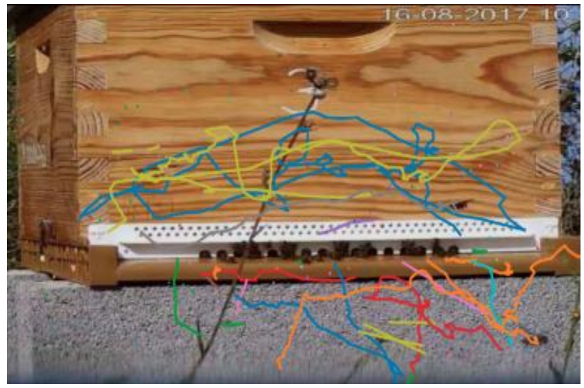

Figure 2: Objects tracked with the V-OUI tracker. The tracking of objects over the course of the video gives trajectories representing the behaviour of the different individuals detected, associated to different colour codes. The fragmentation of certain trajectories suggests that the tracker has sometimes lost its target. The complexity of others trajectories indicates possible tracking errors.

In 2021, a Master 2 internship, financed by the Digital Agriculture Convergence Institute #DigitAg [11], will be undertaken to study the transposition of the coupling (YoloV4 detector, V-OUI tracker) to the specific context of Big Data. In addition to these methodological aspects, it will also be a question of finding the right compromises between video acquisition frequencies, image compression rate with regard to the size of the target objects and calculation times.

Adequacy to the issues of MUSE Data & Life Sciences

This project responds to the major challenges of digital agriculture and the collective intelligence of territories, aiming to develop information systems for the management of *fragile and vital resources* such as bees. It will also provide detailed knowledge helping beekeepers and farmers in the long term to fight against this new predator in order to protect bees and restore their pollination capacities. In this sense, the project falls within the scope of "Big data analysis in agriculture" axis, even if it also partly meets the challenges of the "Statistical Methods for Spatial and Heterogeneous Data - Application in Ecology" axis.

Objectives of the postdoctoral project

The 2020 study identified the main lines of investigation and the scientific locks to be lifted: while it is accepted that Yolo neural networks are effective for the detection of objects [12,13] and their behavior [14,15] in surveillance videos, their application to hornets is not trivial due to their size and apparently 'erratic' movements. To our knowledge, the only detection works concerning bees, wasps and flies have been carried out under artificial lighting and on homogeneous backgrounds [16,17]. The transposition of these works to natural environment is a challenge to take up. The postdoctoral project will therefore, while conducting a bibliographical watch on these constantly evolving aspects, complete and orient the studies conducted during the past and future master internships respectively. It will also address the fundamental scientific questions that guarantee the design, validation and functionality of the turnkey tool to be developed for AMAP ecologists and, in the long term, for beekeepers and agronomists.

Training dataset and data heterogeneity

Beehives are extremely variable in terms of shape, texture, colour and viewing frames. This intrinsic heterogeneity of the field of study is further accentuated by the positioning of the camera in the vicinity of the hive; thus videos taken in front of the hive are potentially more complex to process than those taken from above: the insects are alternately seen from the side, from ¾ front, from ¾ back: the network has to learn different 'expressions' of the object, a bit as if it had to deal with objects in 3D scenes. But it is in the front views that the bee catches can be detected and followed, or the hornet's behaviour can be appreciated. One of the scientific challenges of the postdoctoral project concerns the learning strategy of the neural network.

The goal is to make it as "generic" as possible without causing the collapse of its capacity to detect the different objects of interest: the idea is to make a single "heterogeneous" network functional rather than several "contextualised" networks.

From bee capture detection to hornet behaviour differentiation

The challenge of the 2021 internship is to be able to follow bee captures as accurately as possible, i.e. to produce relevant and continuous trajectories of detected objects (and this independently of the number of objects followed). The second major challenge of the postdoctoral project is to analyse these trajectories in terms of the successive hornet behaviours - visit, hovering, attack, capture, escape - and to study to what extent the annotation of the different parts of the trajectories could allow the specialisation of a neural network for the detection of the hornet's behaviours, because in the end, it is indeed this aspect that ecologists' studies address. This could probably allow to significantly reduce the steps and consequently the costs of video processing.

From the validation of a network to the extrapolation of its performances

This is an important but classic question when moving from a purely scientific to an applied context. Estimating the performances of a neural network is in the end quite simple; guaranteeing its constancy, i.e. its capacity to respond with a constant reliability rate on data sets is more complicated insofar as it is necessary to be able to evaluate the degree of similarity of the data to be processed. This is a crucial point in fields with a high degree of heterogeneity. The postdoctoral project will therefore have to study this aspect in particular by evaluating the solution in different application conditions and trying to correlate the variations in network response to specificities of the data sets.

Towards integrated tools

This is the link between the scientific aspect and the application aspect. The project will ultimately have to provide an integrated solution enabling ecologists to extract from videos the information needed to conduct their various statistical studies on large samples of data.

Means implemented for the success of the project

A consortium with complementary skills

The project involves an interdisciplinary academic partnership gathering agronomists, ecologists and computer scientists with complementary skills, as well as a non-academic partnership directly interested in the results and providing the beekeeping know-how required for its implementation. It is based on a pool of 4 researchers affiliated to the University of Montpellier, including two from the **AMAP** unit (Botany and Modelling of Plant and Vegetation Architecture) and two from the **LIRMM** (Montpellier Laboratory of Computer Science, Robotics and Microelectronics).

Philippe BORIANNE (PB), CIRAD computer scientist, in charge of the AMAP "*Plant and Landscape Imaging*" theme, is a specialist in image analysis and neural networks applied to Agriculture and Agronomy [18,19,20,21]. He set up this project with **Laurence GAUME (LG)**, CNRS ecological scientist 'HDR, CR Hors-Classe', in charge of the AMAP "*Ecology of plant-insect interactions and evolutionary adaptations in plants*" theme [6,7]. LG is concerned by the decline of bees and insects as a whole and has published on the subject with D. Goulson [22], an internationally renowned bee specialist [3]. The strong "digital" orientation of the postdoctoral project and the scientific questions that will be addressed justify the involvement of **Gérard SUBSOL (GS)**, CNRS senior lecturer-researcher, head of the LIRMM "*Images and Interaction*" project team, as specialist in 3D image analysis [20,21,23], and its colleague **Marc CHAUMONT (MC)**, associate professor at the University of Montpellier, 'HDR Hors Classe', as expert in deep neural networks [20,21,23,24]. **Stéphane FOURTIER (SF)**, INRAE assistant engineer, head of the AMAP technical team, in charge of the hive video surveillance service, and **Jean-Luc DELON (JLD),** president of the 'Hérault Beekeeping Health Defence Group, GDSA-34', whose activities are focused on the protection and health of bees, will provide technical support for the postdoctoral project.

Funds obtained and material available

The postdoctoral project, which will take place on the premises of AMAP, is in line with the successive investments attributed to the study of Asian hornet predation. It will benefit from the equipment (bee, hives, cameras) and data (videos) obtained with the initial MUSE CarniVespa 2017-2021 [6] project, which it will in turn support in facilitating the evaluation of the effectiveness of the biomimetic trap. As regards the digital issue of hornet detection and tracking on video images, PB and LG then obtained the funding for a master2 internship in computer science MUSE Kim data & LifeScience DeepHornet

2019-2020 [10] then in bioinformatics #DigitAg DeepBeesAlert 2020-2021 [11] which will strongly support, in terms of preliminary results and human resources, the proposed postdoctoral internship.

Distribution of tasks

JLD is in charge of the maintenance and health protection of the hives. SF takes care of the acquisition of video and meteorological data from the INRA station at the study site. LG deals with the aspects of bee and hornet behaviour and carries out the statistical analysis relating to the ecological issue. PB oversees the (bio-)informatics internships that focus on the use of deep-learning to process videos of hives. The postdoctoral scientist is in charge of developing the numerical tool. He orients the studies of the upcoming Master 2, considering the fundamental scientific questions necessary for the implementation of the methodological tool, while constantly interacting between AMAP and LIRMM researchers. LIRMM scientists bring their expert viewpoint on the deep mechanisms of neural networks and their parametrization (MC) or signal pre-processing of videos before the neural network intervention (GS). The postdoctoral project will thus strengthen the interaction between AMAP and LIRMM, two member units of the I-Site MUSE, which have been collaborating for 3 years on deep-learning aspects [20,21].

Table summarising the distribution of tasks between the different partners

Contribution \ Partner	AMAP /I2P	AMAP / ADAPT	AMAP/ Technical platform	LIRMM/ICAR	GDSA-34
Field	Computer Science applied to Agronomy	Ecology	Agronomy/Ecology	Computer Science	Beekeeping
Expertise	Image analysis Deep neural networks	Biodiversity Insects / Asian hornet	Videosurveillance Meteorology	Image analysis Deep neural networks	Bee health
Site supply	X	X	X		
Material supply	X	X	X		X
Data supply		X	X		
Data analysis	X	X		X	
Logistic support		X			X
Human support	X	X	X	X	X
Funding support	X	X			
Result dissemination	X	X		X	X

References (*The names of the project's actors are underlined in the references.*)

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Short CV of the project head

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Last degree: PhD from the University Louis Pasteur of Strasbourg in July 91 (topology, modelling).

Professional background (key dates):

- 2020→: AgroDeep Project Manager - Neuronal Networks Applied to Agriculture, Agroforestry and Agronomy
- 2015→ : AMAP Imaging Plants and Landscapes manager
- 1991-2001 : co-responsible for the Corpus project: in charge of Orthodontic axes, Maxillofacial Surgery
- 1991 : admission to CIRAD (Amap "Atelier de Modélisation de l'Architecture des Plantes" JRU)

Main valuations

- 2019→: PixFruit technology transfer support (*mangoes and deep neural networks*) – HortSys / Sowit
- 2018-2019 : Scanorhize technology transfer support (*roots and deep neural networks*) – SATTaxlr / Mycea
- 2002-2004 : Corpus-oncology technology transfer support (*mangoes and deep neural networks*) – Cap 'Ω / Intrasense

Research Neural Networks Publications

Zegaoui, Y., Chaumont, M., Subsol, G., **Borianne, P.**, & Derras, M. (2019, May). Urban object classification with 3D Deep-Learning. In *2019 Joint Urban Remote Sensing Event (JURSE)* (pp. 1-4). IEEE.

Zegaoui, Y., Chaumont, M., Subsol, G., **Borianne, P.** and Derras, M. (2018) First Experiments of Deep Learning on LiDAR Point Clouds for Classification of Urban Objects, Congrès CFPT'2018 (Congrès de la société Française de Photogrammétrie et de Télédétection

Applied Neural Networks Publications

Borianne, P., Borne, F., Sarron, J., & Faye, E. (2020). Deep Mango Cultvars: from fruit detection to cultivar identification in colour images of mango trees. *CompAg – sous presse.*

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Applied Images Analysis Publications

Borianne, P., Subsol, G., Fallavier, F., Dardou, A., & Audebert, A. (2018). GT-RootS: An integrated software for automated root system measurement from high-throughput phenotyping platform images. *Computers and electronics in agriculture*, *150*, 328-342.

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Borianne, P., Subsol, G., & Audebert, A. (2016, November). Automated characterization of the mature root system form by a double-quadrangle-shaped polygon. In *2016 IEEE International Conference on Functional-Structural Plant Growth Modeling, Simulation, Visualization and Applications (FSPMA)* (pp. 6-15). IEEE.

Practical information

The candidate will hold a PhD in computer science and data analysis. The candidate should have a strong interest, or even proven skills in image analysis and automatic classification, particularly in machine learning or deep-learning. The mastery of the Python programming language and a sensitivity to Ecology will be appreciated.

The allocation of funding depends both on the adequacy of the subject with the call for projects and on the quality of the post-doctoral student.

The post-doctoral fellowship will take place in Montpellier (France) within the Amap Unit. It will start between February 1 and March 1, 2021 for a period of 12 months.

The basic level of remuneration for a post-doctoral project is 2,585 euros gross per month (or just over 2,000 net). *This cost can be re-evaluated according to the level of technicality and/or professional experience of the candidate.*

For any further information, please contact Laurence GAUME (Laurence.gaume@cirad.fr) AND Philippe BORIANNE (philippe.borianne@cirad.fr) by e-mail.

For any application, please send us a CV and a cover letter.