University – Research – Farm Cooperation to Identify the Halyomorpha Halys Invasion in Orchards

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***Abstract*—Nowadays, multidisciplinary research is found everywhere, especially due to the accelerated development of computer science and information and communication technology in all economic and social fields. In many universities, including the POLITEHNICA University in Bucharest, research as a subject is considered multidisciplinary through case studies and concrete applications. The paper presents a multidisciplinary project implemented under ERA-NET COFOUND, ICT-AGRI-FOOD 2019 Joint Call. This project implies multiple collaborations inside and between different groups: disciplines (computer science-image processing-artificial intelligence-robotics-entomology-agriculture), domains (universities-research-farms), countries, and teams (teachers-researchers-students-farmers). The resulting impact of this collaboration is also multiple: educational, economic, and social. From an educational point of view, the results consisted of course chapters, themes for undergraduate, master, and doctoral degrees, and papers in important international conferences or journals made by teams of students, researchers, and professors.**

Keywords — multidisciplinary approach, multinational project, research – education - farm cooperation, undergraduate - master - doctorate - professor team, aerial robots, insect detection, image processing, artificial intelligence

I. INTRODUCTION

Recently, the multidisciplinary approach in research activities [1] demonstrates a series of indisputable advantages for the implementation of complex projects or for understanding the solution of problems faced by the different fields of human activities. In 2020, a multidisciplinary project based on international funding (ERA-NET COFOUND, ICT-AGRI-FOOD 2019 Joint Call) - HALIY.ID ("HALYomorpha halys IDentification: Innovative ICT tools for targeted monitoring and sustainable management of the brown marmorated stink bug and other pests") - was won for the realization of an integrated, intelligent system for the detection, evaluation, modeling, and monitoring of the Halyomorpha halys (HH) population in orchards [2], [3]. Because technical universities offer the opportunity to cooperate to implement such research, a consortium of five universities and a research center from different European countries are collaborating for the realization of this complex project. On the other hand, the practical activities of computer science students in various other fields such as robotics, agriculture, entomology, environmental protection, etc. can lead to the formation of valuable specialists.

The Halyomorpha halys [4], [5] is an invasive emerging pest of global importance for many agricultural crops and, also, a household nuisance due to the overwintering aggregations inside man-made structures. Due to its hitchhiking features, HH has rapidly spread since 2004 throughout the European continent, where it is currently reported to have established populations in 28 countries. Both adults and nymphs feed by piercing and sucking on a great variety of fruits and seeds, rendering products unmarketable. The project is a solution based on an ICT platform to improve the sustainability of agri-food systems. The main research objectives of the HALY.ID project are the following: (1) Designing and implementing an innovative autonomous field data acquisition system. to detect HH and other pests; (2) Designing and implementing a classification system to detect fruit damage that is not visible to the naked eye; (3) A software solution, based on ML techniques, to obtain the most as far as possible the epidemiological pattern of HH and/ or other pests [3]. These objectives are met in partnership with six universities and research centers in the European Union: UNIPG (Università Degli Studi di Perugia) as coordinator and partners UNIMORE (Università Degli Studi di Modena and Reggio Emilia), TUBS (Technische Universität Braunschweig), TNI (Tyndall National Institute, University College Cork), IMEC (OnePlanet Research Center), UPB (POLITEHNICA University of Bucharest). HALY.ID is a collaborative project between universities (one of them as coordinator), research institutes, and economic units (farms and production units as end users and experimental areas) in the field of modern agriculture (orchard farms). In the POLITEHNICA University of Bucharest, through case studies and concrete applications, research in the university curriculum is considered multidisciplinary.

The project is implementing between 2021-2024, through common efforts of teachers, researchers, students, and farmers from various European countries (Italy, Germany, Ireland, the Netherlands, and Romania). By integrating multidisciplinary skills (aerial robots, image processing, artificial intelligence, modeling, entomology, horticulture), the project will help farmers and phytosanitary staff to achieve a high-performance real-time HH invasion monitoring system with low energy and costs, reducing the number of chemical treatments. This paper is focused on the UPB work to implement the corresponding activities. All partners have similar activities.

As emphasized in [1], [6] multidisciplinarity can be considered as a convergence of the same theme, through multiple fields of knowledge. This is the main characteristic of the project and involved the collaboration of UPB with specialists of NARDI (National Agricultural Research and Development Institute) Fundulea (for entomology research). On the other hand, the use of aerial robots (UAV – unmanned aerial vehicles) in educational activities [7] and agriculture has gained a special advantage. The use of UAVs was considered essential in collecting data and images from the orchard.

The educational impact was manifested by all European partners. In addition to the researchers' interest in implementing artificial intelligence-based solutions, the project has a positive impact on the educational process expressed by students' interest in implementing certain sections of the project and through the introduction by the teachers in the chapters of the specific courses of mobile robots and advanced image processing. The interest areas were designing and tracking drone flight paths inside orchards, processing images from drones through neural networks, and modeling the evolution of HH according to the characteristics of the environment. This interest is manifested by the elaboration of undergraduate degree theses, master theses, doctoral theses, and papers at international conferences and important journals on the project topics. On the other hand, UPB academic staff and researchers had the opportunity to probe new concepts and implement new courses and laboratories. Farm specialists had the opportunity to learn the theoretical and practical fundamentals of new discoveries in the field.

II. Methodology

The multidisciplinary character of the project consists of the involvement of several disciplines for its implementation: robotics (aerial robots), computer science, image acquisition and processing, artificial intelligence, agriculture, and entomology. These were partially disseminated in the papers published by the project team. All papers are developed including student efforts as co-authors.

Fig. 1 presents the main stages that the students must follow to automatically identify the HHs [8]. The images for learning and validation were taken from the datasets mentioned in Table I. After image acquisition by UAV on a corresponding flight (a special trajectory), there are two preparatory stages for both the learning and the testing phase: image resizing and data augmentation.

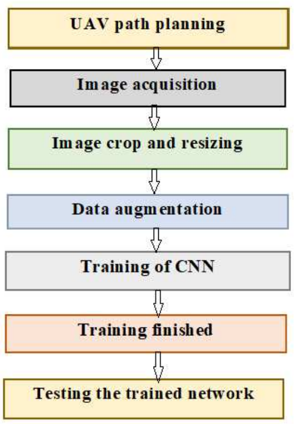

Fig. 1. Diagram of signal processing for HH detection.

Materials used to implement the proposed project, such as neural networks and aerial robots are considered state-of-the-art technology (Table I). As a novelty, the neural networks studied will be considered primary classifiers for HH detection (PC_i in Fig. 2) and incorporated into a decision fusion system based on the (statistical) performances of the studied networks. The system provides for the use of the five most-performing networks. The number is chosen as a compromise between efficiency and complexity. Since when acquiring images (I) from the UAV (distance 0.5 m from the crown of the trees) the insects occupy a small space of the total surface of an image, the division of the acquired image into sub-images (P_{ij} patches) by the ID module and their analysis by the primary classifiers was foreseen. The studied neural networks were classified according to the statistical performances measured in HH detection, each receiving a score w_i (weight) in the learning phase. Since PC_i outputs the probability p_i that the analyzed patch Pij contains HH, the final classifier block (FCB) decides that Pij contains HH if the sum of the weighted probabilities $\Sigma p_i w_i$ exceeds a predetermined threshold.

The complex activities and expected results for the project personnel, students (undergraduate, master, and Ph.D.), and third parties - farms (orchards) are presented in Table II.

TABLE I. Materials Used in Licence-Master-Doctoral Research Connected with HALY.ID Project.

Materials	Representatives
Neural Networks	DenseNet201, ResNet101, GoogLeNet, VGG 19, YOLOv5s, SSD/ MobileNet V1, SSD/ MobileNet V2, SSD/ ResNet50, EfficientDet-D0, Faster R-CNN/ ResNet50
Datasets	Maryland Biodiversity and own (acquired by UAV or operator with RGB or multispectral cameras)
UAV	Matrice 600, Phantom 4 RTK, and Mavic 2 Pro DJI

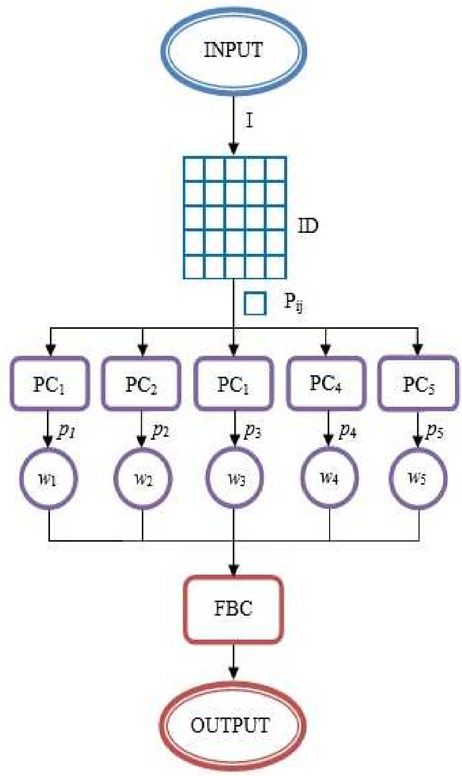

Fig. 2. Decision fusion system based on five neural networks as primary classifiers

TABLE II. PERSONNEL STRUCTURE, ACTIVITIES, AND EXPECTED RESULTS FOR THE UPB TEAM (STAFF FROM THE PROJECT AND STUDENTS WITH SIMILAR RESEARCH TOPICS)

Staff from the project: researchers, professors, associate professors/ 7	
Activities	► UAV algorithms and software for navigation: trajectory generation for orchard mapping (2D) and inspecting trees (3D). ► Algorithms and software for image acquisition. ► Creating the database for HH in the orchard ► Design of an intelligent system based on convolutional neural networks for HH detection. ► Development of the epidemiological model for HH ► Modelling the HH abundance and evolution. ► Establishing practical, research, licensing, master, and doctoral themes related to the project. ► Dissemination of the results.
Expected results	●HALY.ID concepts, design, experimental model, research reports, test reports, ●Paper publication, ●Technology transfer, ●Patents, ●Establishing licensing, master, and doctoral subsidiary themes and projects.
UPB – undergraduate, master, and Ph.D. students/ Number of students – undergraduate: 4, master: 4, Ph.D.: 2	
Activities	► Testing the proposed CNN ► Virtual and real experiments in the orchard ► Software for UAV navigation in the orchard. ► Software packages for image processing. ► Modelling the HH abundance and evolution. ► Dissemination of the results.
Expected results	●Hardware and software modules. ●Research reports. ●Licensing, master, and doctoral thesis. ●Paper publication.
Services performed by third parties - farms (orchards)	
Activities	► Identification of areas with HH in ecological orchards ► Provide UAV flight testing ► Ensuring the experimentation of the intelligent system for the detection and identification of HH.

Within the project, complex and difficult research or implementation problems are encountered, which are shown in Table III. Modern, innovative solutions that will be solved with the involvement of students are also shown in Table III.

The project objectives and activities for UPB reveal the educational, research, and farm requirements of the project from the perspective of the people (specialists) involved.

TABLE III. COMPLEX PROBLEMS DISCUSSED IN THE EDUCATIONAL PROCESS.

Problems	Solutions
3D navigation of UAV in the orchard near trees	●3D trajectory design. ●Digital mapping of the orchards using orthophotography. ●Vertical orthophotoplan.
Image processing and detection of HH in the real environment (orchard).	● Multi-neural network approach based on decision fusion to improve HH detection. ● Using multispectral cameras combined with RGB cameras. ● Creating an original dataset with insects containing HH from images acquired in orchards.
Epidemiological model and abundance detection for concrete orchard	● Measuring meteorological conditions. ● Following the development of the insect in real conditions (nets in the orchard) ● Establishing a mathematical model regarding the spread of insects in the tree, taking into account the appearance of the tree and the number of insects detected when sweeping the tree in the flight of the drone

III. EXPERIMENTAL RESULTS

The experimental results of the students, guided by professors or experienced researchers, have been highlighted both in the development or completion of undergraduate, master, and doctorate theses, as well as in the support and publication of valuable articles at prestigious conferences in multidisciplinary fields. To create their own data sets, the students performed authorized flights with the drones mentioned in Table I. With the acquired data and using artificial intelligence techniques (neural networks), the students performed a series of experiments that are mentioned in Table IV.

Examples of images from different stages of student experiments are given in Fig. 3. The significance of the images is as follows: a.1– Image for orchard mapping (horizontal flight of UAV). a.2 – UAV in orchard inspection with PHANTOM 4 RTK (3D flight). a.3 – Elevation map. b1, b2 – 3D reconstruction of the orchard from the images taken from the drone. b.3 – Dual system proposed by UPB team to reduce false negative and false positive errors. c.1 – Image containing HH acquired with a smartphone. c.2 – Image containing HH acquired with a UAV Mavic 2 PRO. c.3 – NIR image containing HH acquired with a multispectral camera Parrot Seqouia+. d.1 – HH nympha in the orchard (learning dataset). d.2 – HH adult in the orchard (learning dataset). d.3 – NonHH insect in the orchard (learning dataset). e.1 – (testing dataset) HH original, e.2 – (testing dataset) HH detected by Faster R-CNN. e.3 – HH detected by YOLOv5-s. The system proposed in Fig. 3. b.3 consists of two neural networks, one (Yolo) to reduce the false negative and the other (Efficient Net) to reduce the false positive errors The pyramidal ROI segmentation mechanism [11] is used for optimal detection of a patch containing HH.

The educational and research impact on the students manifested in dissemination through papers can be seen in Table V and Table VI (D - Ph.D. student, M - master student, (U - undergraduate student, and P - professor). In most papers, the students are the first authors.

TABLE IV. STUDENT EXPERIMENTS ON HH DETECTION USING NEURAL NETWORKS.

Experi-ment	Methodology/ NN used	Performance	Observations
E1	● Shape features and texture features of HH	NA	● Shape features, fractal dimension, and lacunarity, ● HH adult
E2	● Modified Single Shot Detector (SSD)	● IoU (Intersection over Union) [%]: 70.2	● HH adult
E3	● Faster RCNN,	● ACC (accuracy) [%]: 89%	● HH adult and nympha, Nezara viridula, Pyrrhocoris apterus
E4	● YOLO v5s,	● Testing time [ms]: 6; 0.3; 0.8; 1.6	● Local machine powered by a GPU NVIDIA GTX 1070
E5	● SSD with MobileNet V1 backbone,	● Precision [%]: 73.8 - 95.3;	● HH adult, HH nympha
E6	● SSD with MobileNet V2, backbone,	● Recall [%]: 88; 88.3; 98.4; 75.4	● HH adult, HH nympha
E7	● SSD with ResNet-50, backbone,	● mAP [%]: 89.1; 89.4; 99.2; 77	● Python 3.9, TensorFlow 2.7 developed by Google,

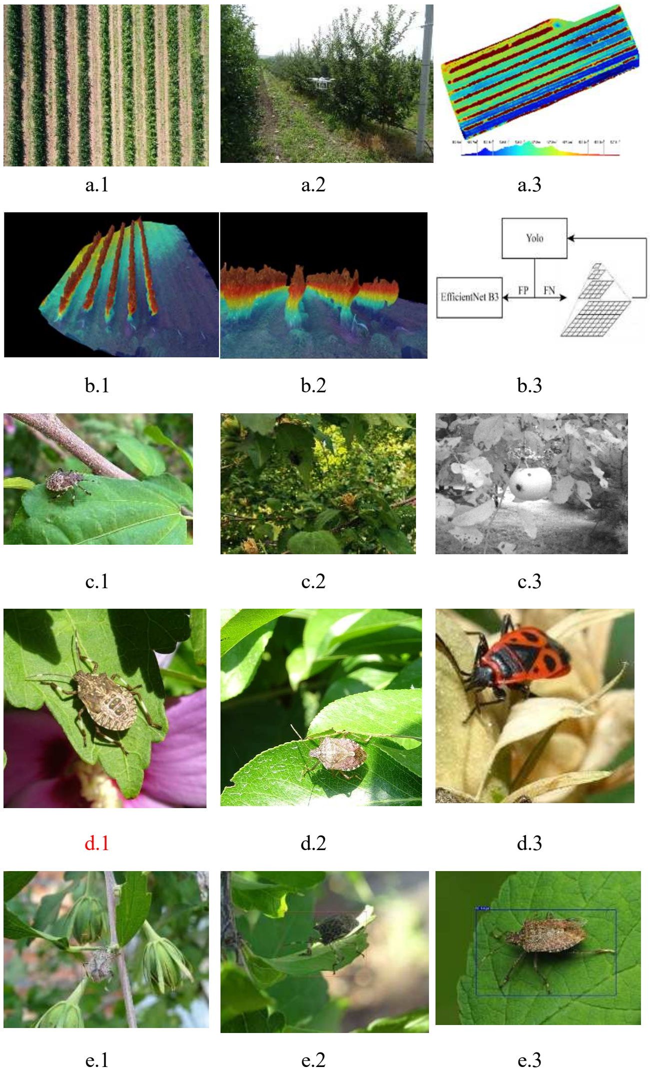

Fig. 3. Examples of images from different stages of student experiments.

TABLE V. EXAMPLES OF RESEARCH, UNDERGRADUATE, MASTER, AND DOCTORAL THESES IN UPB COLLECTIVE. (D - PH.D. STUDENT, M - MASTER STUDENT, U - UNDERGRADUATE STUDENT, AND P – PROFESSOR)

Theme	Multidisciplinary topics	Obs.
Designing the flight path for UAV tree segmentation and leaf volume determination	• Aerial robots; image acquisition and processing; agriculture	U
Designing the 3D flight path for UAV in an orchard for tree inspection	• Aerial robots; image acquisition and processing; agriculture; entomology	M
Algorithms based on artificial intelligence for the detection of harmful insects in organic agriculture	• Image acquisition and processing; agriculture; entomology	M
Data analysis through artificial intelligence techniques to estimate the degree of spread of harmful insects in orchards	• Robotics; artificial intelligence; agriculture; entomology	D
UAV-WSN collaboration for the acquisition of meteorological data from agricultural crops	• Aerial robots; sensors; data acquisition and processing; agriculture	U
Implementation of a global decision system based on multiple neural networks for HH detection	• Entomology; image processing; artificial intelligence	D
Establishing an epidemiological model of HH	• Entomology; artificial intelligence	M
Detecting fruit defects through artificial intelligence techniques.	• Agriculture; image processing; artificial intelligence,	U

TABLE VI. DISSEMINATION OF THE RESEARCH RESULTS BY COLLABORATIVE EDUCATIONAL TEAMS (STUDENTS – B, M, D, AND PROFESSORS).

Authors	Paper	Ref.
(U) Trufelea, R. (D) Dimoiu, M., (P) Ichim, L., Popescu, D.	• Detection of Harmful Insects for Orchard Using Convolutional Neural Networks	[9]
(D) Dimoiu, M. (P) Popescu, D., Ichim, L.	• Improved Conditional GAN for Aerial Image Segmentation	[10]
(M) Sava, A. (P) Ichim, L., Popescu, D.	• Detection of Halyomorpha Halys Using Neural Networks	[11]
(U) Trufelea, R. (D) Dimoiu, M. (P) Popescu, D., Ichim, L.	• Comparative Study of Neural Networks Used in Halyomorpha Halys Detection	[12]
(M) Ciciu, R. (P) Ichim, L., Popescu, D.	• Using Drones and Deep Neural Networks to Detect Halyomorpha Halys in Ecological Orchards	[13]
(D) Serghei, T.L. (P) Popescu, D., Ichim, L.	• Dual Networks-Based System for Detecting and Classifying Harmful Insects in Orchards	[14]
(D) Dinca, A. (P) Ichim, L., Popescu, D.	• Halyomorpha Halys Detection Using Efficient Neural Networks	[15]

IV. CONCLUSIONS

From an educational point of view (bachelor's degree, master's degree, doctorate) some aspects of methodology were introduced in the courses' chapters. The experimental results of the students offered by the platforms established within the multidisciplinary project contributed to the completion of undergraduate, master, or doctoral theses. Also, they were disseminated in papers published in the volumes of prestigious conferences or specialized journals. Globally, it can be said that the project contributed to the modernization of some disciplines in higher education at UPB.

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