A Multi-level Smart Monitoring System by Combining an E-Nose and Image Processing for Early Detection of FAW Pest in Agriculture

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Abstract. Fall Armyworm whose scientific name is Spodoptera frugiperda is a pest which have a large destructive activity of cornfields in sub-Saharan Africa. Fall Armyworm is a pest causing significant economic harm in Africa. In this work, we proposed to develop a smart monitoring system through several level. Each level of the proposed monitoring system is used to control and to detect the pest early. The aim is therefore to develop a system for the early detection of fall armyworm, these eggs, larvae and its adult form on image in order to anticipate the damage it can cause and to prevent its proliferation. First of all, the proposed monitoring system is based on an e-nose to analyze the odors that are released in the environment by fall armyworm. Then, we use image processing techniques based on image segmentation to detect the presence of pest through the damage caused to the plants and leaves its environment. We offers through this work, a smart monitoring system for Early Detection of FAW (EDFaw) by combining an e-nose and the plant leaf image segmentation. Several experiments have been done to test the proposed system and the results of the image segmentation.

Keywords: Smart farming · Fall Armyworm (FAW) · Multi-level monitoring · Early detection · E-nose · Image processing

1 Introduction

West African countries benefit from climate and favorable terrain for agriculture. This agricultural potential enables the countries of this zone to cultivate a good number of seeds such as maize, cowpeas, rice, yams, pineapples, palm nuts [1]. Agriculture is an important pillar for development of countries despite the efforts that are made to secure it. It has many difficulties such as the invasion of insect pests. Pest control plays a crucial role in farming for without it, plants will die or not bear fruits. Pests are a natural enemy to farmers because they hinder farm production [1]. Farmers have to use different methods

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of controlling pests. Common forms of pest control involves traps usage, field burning, air guns, hunting, using poisoned bait, natural rodent control, destruction of infected plants, poison spraying, sterilization, and eliminating breeding grounds through drainage of still water or proper management of waste. By implementing one of these methods, farmers can fully maintain the sound health of their farms and agricultural produces. However, these techniques are main factors in soil water contamination and soil depletion. Another solution is the use of Genetically Modified Organisms (GMOs) [1], which have proved to be very effective but with no impact on the environment. Thereby, apart from the various ethical problems they raise, they also lead to health complications for both consumers and farmers. Nevertheless, monitoring pest population is important and it is currently a key issue in crop protection. In a farm, it is fluently operated by repeated surveys by a human. This is a task and time consuming activity, and it would be important for farmers to have an efficient system of doing this work automatically. To fix this problem, we propose to design a smart sensor implanted in wireless network which uses an electronic nose architecture that is able to monitor the smells level characterizing the arrival of pests in the farm.

The main goal of this work is to propose smart systems for digitizing agriculture. All this contributes to the development of a smart, precise and ecological agriculture to address the harmful effects of climate change, depletion of agricultural production resources, environmental unfriendly methods struggling against pests. A review of different methods of fighting against pests and specifically the fall armyworm tells us that this problem is still relevant. No solution now offers a safe guarantee to farmers against pest attacks. Agricultural activities monitoring is an important tool in the early detection of plant diseases from symptoms at the parasite control stage during flowering and maturity. Indeed, in the phase of pest control in order to resist plant diseases in agriculture, the current solution requires the massive use of phytosanitary products that are dangerous for crops, the agricultural environment, and the health of both farmers and consumers [2].

Another purpose of this work is to respond to a new agronomic challenge in the context of agro-ecology through the development of a new method of pest control by using a smart crop monitoring system. Then, we propose a new approach to the fight against fall armyworm by proposing a multilevel monitoring strategy for the early detection of the pest on the cornfields. The proposed strategy is based on smart sensors by combining of a set of usual agricultural parameter measurement sensors (temperature, humidity) and electronic nose type sensors for the measurement of volatile substance in environment of the caterpillar using a brand new electronic system designed in order to detect caterpillar. The data provided by such sensors have to be collected in a way that reduce the energy consumption of the sensors as they could be in place for several month periods. An unmanned aerial vehicle will be used to fly over crops to gather sensors data such a detection method would contribute to the establishment of an effective control protocol against fall armyworm as soon as it is detected near crops. This would reduce the use of plant protection products, pesticides and the uses of GMOs, or considerably reduce the quantities usually used [4]. Also to use bio-pesticides at the appropriate time of the development of fall armyworm to annihilate it. This ecological method will therefore make it possible to fight efficiently against the fall armyworm while respecting the environment.

The paper is organized as follows. A Sect. 1 relates a context of this work and provides an overview of current methods of FAW control. In Sect. 2, we review the current computers tools for control fall Armyworm. Section 3 described the proposed a multilevel monitoring system for FAW early detection. Section 4 is devoted experiments results and discussion.

2 Current Struggle Methods Against Fall Armyworm

Many methods to control FAW are already being proposed and exploited. These approaches can be summarized in two broad categories: biological or biotechnological and behavioral approaches.

2.1 Biological or Biotechnological Approaches

Genetically Modified Organisms: To control pests, one of the recommended techniques is the use of genetically modified organisms (GMOs). Thus, although not developed for FAW, the trans-genic maize called "maize BT" has been controlled in Africa. Maize has been genetically modified by integrating genes from the Bacillus thurigiensis (BT) bacteria that produces insecticidal proteins that kill crop pests. The use of BT maize has in some cases, led to a reduction in insecticide use, pest control, and conservation of beneficial natural enemies and higher profits for farmers. However, these benefits may be short-lived because insect populations are able to adapt to BT proteins through the evolution of resistance [3]. Indeed, Spodoptera frugiperda has developed resistance to BT Maize in America and stem borers (Busseola fusca) have done the same less than two years after the deployment of BT Maize in the fields. Also, the ratio between the costs of supplying transgenic maize and the non-intensive production of most farmers makes it difficult to use this solution in the long term. It should also be noted that the consumption of products derived from transgenic plants is a cause of diseases such as cancer.

Pesticides: It involves the use of natural elements such as lime, salt, oil and soap as control measures to reduce the use of chemical pesticides. Lime and ash are very alkaline. Farmers also use local botanical pesticides (neem, chilli, local plants) [5]. However, this technique is expensive for people who do not always have the desired result. This leads to a high use of chemical pesticides with its disadvantages, which are soil contamination and groundwater contamination.

Fertilizers: Several studies have shown the effect of corn fertilization on the growth and mortality of FAW larvae and sometimes even the difference in the effects of FAW when using chemical fertilizer or organic fertilizer (manure). Differences between the two types of fertilizer were observed on: FAW larval growth, presence of natural enemies, FAW larval mortality, and cornfields infestation levels (percentage [%] of infested plants). However, in Brazil, chemical ferti-lizer resulted in significantly higher levels of FAW infestation in maize than treatments that did not use fertilizer, or organic fertilizer. The use of chemical fertilizers also impoverishes the soil and makes subsoil water unsuitable for consumption.

Natural Enemies: Some plants (e.g. beans and squash) are natural enemies of FAW because they emit chemicals that the caterpillar does not like. These volatile compounds are therefore natural "re-pellents". Also, some plants (Tagetes lucida, Coriandrum, Sonchus oleracea, Ruta, onions etc.) at-tract or facilitate the proliferation of insects that are predators for FAW. These animals harmful to FAW include predatory mite insects (Earwigs or Forficules, Terrestrial Beetles, Ladybugs, Spiders, Wasps, Bedbugs, Ants, etc.) that eat their prey, microbial parasites and pathogens (such as nematodes, fungi, bacteria, viruses and protozoa) that cause deadly infections and parasitoids. During inventories in the western hemisphere, nearly 150 different species of parasitoids have been found to be associated with FAW in various crops [6]. These natural enemies, although they are naturally present in agricultural areas, do not allow for a real control against FAW attacks. A deliberate increase in these natural enemies would also cause an imbalance in the ecosystem of the cultivation areas, thus posing a real ecological problem.

2.2 Behavioral Approaches

Managing FAW in maize fields begin with prevention. Some steps are recommended to farmers to reduce the impact of FAW on their fields.

Crop Management: Some approaches are recommended to farmers to reduce the impact of FAW on their fields.

Harmonize the Sowing Date: This method consists of harmonizing the sowing date, which means avoiding staggered sowing in the same area, as this would help to provide the FAW's favorite food locally, namely young maize plants. This is one of the most important recommendations for small producers. As mentioned above, in January 2018, some farmers in Kenya reported significant yield losses due to FAW on late planted maize plots compared to neighboring plots that had been planted earlier. This natural method only reduces the extent of damage to crops.

Agricultural Diversity: Diversity on the farm reduces the infestation of fall armyworm larvae and is favorable to natural enemies. Indeed, FAW females prefer to lay their eggs in corn. In a corn monoculture area, all the female has to do is fly over and lay these eggs and the contamination is done. But, when maize is grown in combination with other crops it is more likely to move, ignoring maize plants. Central American farmers have noticed that when they plant maize with other crops such as beans and squash (their traditional "milpa" systems), they have fewer pest attacks [7]. This method is also natural but does not protect farmers from attacks rather it just limits the damage.

The Push-Pull Technique: On the one hand, it consists of planting seeds around the cornfields that attract adult FAW females who leave their eggs there. On the other hand, insert seeds in maize plants that emit volatile compounds that repel FAW.

Awareness Platform: In order to raise awareness and keep the population informed about the various events related to the FAW, an awareness platform was developed by Bello-Bravo and collaborator in 2018. This platform is intended to be accessible to people with low literacy skills. Awareness platforms are very effective for sharing information. However, it does not allow us to be reactive enough and we are sometimes subject to false information from Internet users. The study of these different control techniques allows us to summarize their performance in Table 1.

Table 1. Performance summaries of FAW control systems.

Control technique	Ecological	Cost	Speed of detection	Efficiency and effective ness	Health problem	Autonomous	Production Quality for health
Pesticides	No	High	No	Average	Yes	No	Bad
GOM	No	High	No	Average	Yes	No	Bad
Fertilizers	No	High	No	Average	yes	No	Bad
Natural enemies	Average	Low	No	Average	No	No	Good
Crop management	Yes	Low	No	Average	No	No	Good
Awareness-raising platform	Yes	Low	Yes (average)	Average	No	No	Good

3 Computer Tools Based Approaches for Struggle FAW

3.1 FAMEWS: FAW Monitoring and Early Warning System

The FAW Monitoring and Early Warning System (FAMEWS) is a free mobile application for Android cell phones from the Food and Agriculture Organization of the United Nations (FAO) for the real-time global monitoring of Fall Armyworm (FAW). This multi-lingual tool allows farmers, communities, extension agents and others to record standardized field data whenever they scout a field or check pheromone traps for FAW. Data from the app provides valuable insights on how FAW changes over time with ecology, to improve knowledge of its behaviour and guide best management practices. All collected data are used by FAO, countries and partners to map and monitor current infestations [10]. The app is designed to expand with the evolving needs of farmers, analysts and decision-makers, and can be used anywhere in the world. Fall Armyworm (FAW) (Spodoptera frugiperda), is an insect pest of more than 80 plant species. The larval stage of the insect causes dam-age to economically important cultivated cereals such as maize, rice, sorghum, and to vegetable crops and cotton. The pest is native to tropical and subtropical regions of the Americas. It was first detected in Central and Western Africa in early 2016, and has quickly spread across virtually all of sub-Saharan Africa. Because of trade and the moth's strong flying ability, it has the potential to spread further. Maize is the most infested crop in Africa.

3.2 Nuru

Nuru is an app that uses cutting-edge technologies involving machine learning and artificial intelligence. It runs on a standard Android phone and can work offline. "The new tool will help farmers recognize their new enemy and take immediate measures to stop it. Nuru becomes African farmers' newest ally against Fall Armyworm. Fall Armyworm first appeared in Africa in 2016, in West Africa, and then rapidly spread across all countries in sub-Saharan Africa in 2017, infecting millions of hectares of maize, and threatening the food security of more than 300 million people.

Many African farmers might have heard about Fall Armyworm but are seeing it for the first time, and are often unable to recognize it or unsure what they are facing. With the new application, they can hold the phone next to an infested plant, and Nuru can immediately confirm if Fall Armyworm caused the damage.

Nuru is a new tool will help farmers recognize their new enemy and take immediate measures to stop it. It complements FAO's recently launched Fall Armyworm Monitoring and Early Warning System (FAMEWS) mobile application [8], which builds knowledge on how and where the pest spreads, and what makes it less damaging," said Keith Cresman, FAO Senior Agricultural Officer who leads FAO's digital response to Fall Armyworm and other pests. An important feature on the new tool is that it can work offline so farmers can use it whenever they want it [9].

4 A Multilevel Architecture of a Smart Monitoring System for Early Detection of FAW

Through a study of different control methods of FAW, we can retain that the Fight against FAW is still relevant. Indeed, no solution at present offers a security guarantee to the farmer against FAW attacks. In this work, we propose a new approach to the control of FAW by build a multi-level monitoring strategy for the early detection of FAW on the field based on a combined set of agricultural parameter measurement sensors on one hand and electronic nose type sensors for the measurement of volatile substances in the track environment on the other hand. This technique represents a new approach in the fight against FAW because it uses an electronic system for automatic FAW detection. Such a detection method would contribute to the implementation of an effective control protocol for FAW as soon as it is detected in the vicinity of the crops. This would be achieved by no longer using pesticides and GMOs, or by significantly reducing the quantities usually used. But also to use biopesticides at the appropriate time in the development of FAW to annihilate it. This ecological method will therefore make it possible to control FAW effectively and in an environmental friendly way. The new approach to combating FAW comes from careful observation of FAW.

4.1 Level of Early Detection of FAW

Based on the life cycle and Behavior of the Fall Armyworm, we propose four level of fall armyworm detection.

Detection Level 1: The earliest phase to detect the presence of FAW in fields is the detection of adult FAW before it reaches the fields. We could then react (by setting up chemical barriers around crops for example) and prevent the intrusion of FAW into crops.

Detection Level 2: If it is not detected at the level 1, it must therefore be possible to detect the presence of FAW in the fields as soon as the intrusion occurs.

Detection Level 3: The third level consists of detecting the eggs laid on the leaves and this within a maximum of three days before the eggs hatch. This step is crucial in detection because FAW is at a stage in its life cycle that precedes the attack on crops. After hatching, we are the larval phase, which is the phase where the caterpillar creates the most damage. Its presence is materialized by the damage created on the plants. At this level, we used image-processing method to analyze the plant leaf images acquired by segmentation methods and to make a separation into several classes of images. This toil enables to detect the fall armyworm eggs, larvae and its adult form on images in order to anticipate the damage it can cause and to prevent its proliferation.

Detection Level 4: That is the last level of detection allows the caterpillar to be identified before it goes underground to become adult and proliferate. At this stage, Detection is no longer early, but it is still possible to react before the infection spreads and interrupt the life cycle of the first generation of FAW in the vicinity. The early detection level is therefore subdivided into four step summarized in the Table 2.

Table 2. Different levels of FAW detection

	Detection level			
	Early detection			Detection
Level	Very	Average	Few	Starting of the attack
Detection moment	Before adult FAW coming in the crops	Upon adult FAW entering in the crops	Detection of FAW eggs	Detection of larvae or attacks on leaves

The below diagram (Fig. 1) related the proposed algorithm of fall armyworm multi-level detection. This diagram describes the sequence of different actions according to the monitoring system levels. Indeed, the first level of monitoring is based on the pheromone approach. At this step, the electronic nose is used to detect the volatile and odoriferous substances characterizing the early presence of the fall armyworm.

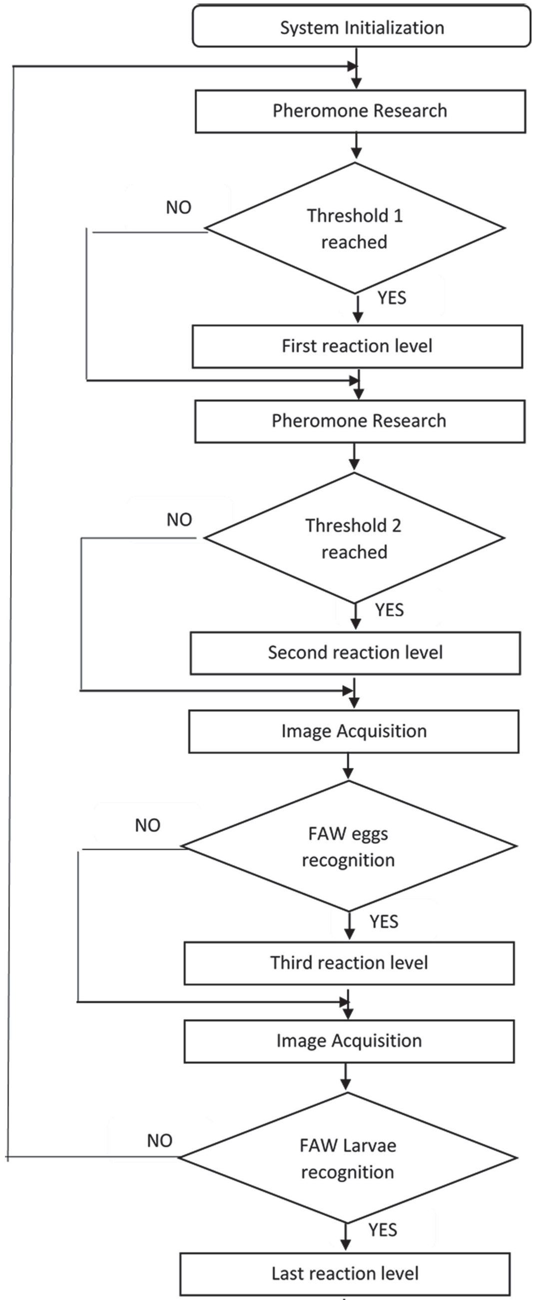


Fig. 1. The proposed algorithm of fall armyworm multilevel detection.

1. A deduction threshold is set in relation to the measurements of the chemical components performed by the electronic nose.
2. If the set threshold is reached, an early detection alarm of the caterpillar in the field is triggered so that more efficient control measures are triggered.
3. In the opposite case where the set threshold is not reached, the second level of monitoring is triggered which uses a computer vision system of image processing by the segmentation of the images of leaves of plants. At this stage, image segmentation can detect the presence of eggs or larvae of fall armyworm.

4.2 A Multilevel Monitoring System for Early Detection of FAW

The FAW first two detection levels are based on the identification of female FAW pheromone secretion. The density of pheromones identified help to know if the adult FAW is yet to be around crop or if it is already been there. This mainly involves the detection of (Z)-9-tetradecenyl acetate (Z-9-14: OAca) contained in the sexual pheromone of Spodoptera frugiperda. The last two detection levels are based on the volatile substances emitted by the plants when they enter into contact with adult FAW when plants are digested by FAW and when eggs are laid. At the fourth level of the system, we use image segmentation techniques to detect the damage and damage caused by caterpillar attacks on corn leaves.

First and Second Levels. Electronic structure of the FAW detection system based on the Electronic Nose. Fall Armyworm detection is based on an electronic nose and decision making system. The electronic nose is subdivided into three main parts. The proposed architecture for detection is shown in Fig. 2.

- **The air sampling system:** This is an important part of the system which allows the air sample to be taken for analysis. It is the mechanical part of the system that consists a metal enclosure equipped with solenoid valve and pump to control the air to be analyzed in the measuring enclosure.
- **The detection system:** This part is organized around of a group of sensors and signal conditioning circuits that are the reactive parts of the E-nose. It is mainly based on

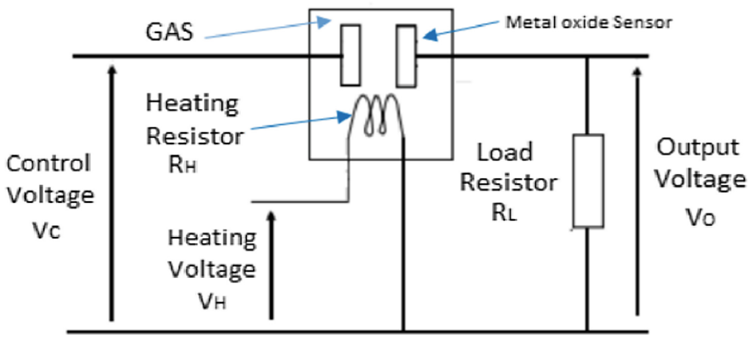


Fig. 2. Circuit diagram of the conditioning circuit of a metal oxide gas sensor.

semiconductor type metal oxide (MOSFET) transducer or resistive sensors that are installed in the measurement enclosure. Their electrical parameters (conductivity, resistivity) are modified as soon as they enter into contact with volatile substances such as pheromones. V_o is the Output voltage of the E-nose of which is computed by Eq. (1) based on G_{MOS} estimation through to use V_c and V_o with the resistor R_L by Eq. (2). With GMOS the conductivity of the Metal oxide sensor.

$$V_0 = \frac{R_L}{R_L + \frac{1}{G_{MOS}}} V_C \tag{1}$$

$$G_{MOS} = \frac{1}{R_L} \times \frac{V_0}{V_C \times V_0} \tag{2}$$

- **The computer processing system:** Processor is a main component of this part. When the sensors detect a volatile substance, a specific response corresponding to the digital measurement of all sensors is recorded and accessible in one memory.
- **The decision system:** This part is very important in the detection system because it takes the data from the E-nose and compares them with specific signatures of the pheromones and volatile substances sought to identify the presence of FAW. Many methods can be used to realize pattern recognition, in our case signal profile recognition. The non-parametric method based on neural networks, for example, it is based exclusively on measured data for signal characterization. See in Fig. 3, the global architecture of the E-nose system to monitor the specific odor of the fall armyworm.

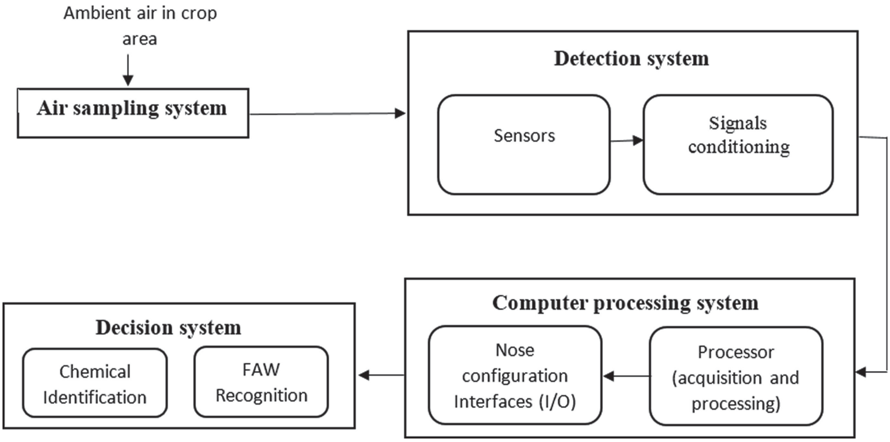


Fig. 3. Structure of FAW detection system.

Levels Third and Four. Image processing Tools for Early Plant Diseases Detection on Leaf. Fall Armyworm detection is also based on plant leaf image segmentation. We use region-based segmentation approach in a credibility context [2]. This approach has the advantage to take into account the segmentation model of all the sources of noise during the acquisition step. We proposed to use a new segmentation method which we develop in the context of plant disease leaf detection by combining three features and the potential noise source using TBM Framework. In our approach, we used the framework of transferable belief function to model the different potential sources of acquisition noise that are taken into account when extracting image features that have been negatively impacted by its noise. Hence, the robustness of the proposed technique against noise [2]. In addition, different features of the image were extracted and merged into one by exploiting the cautious information combination rules provided by the TBM tool to enhance the sowing performance and power of the segmentation algorithm. Experimental results show that the proposed method is appropriate for dealing with plant disease leaf image segmentation and has certain robustness for noise, and effective and accurate image 0segmentation method in the field of plant disease detection [12]. In the future, we will further compare the potential benefits and limitations of the other categories existing method against image segmentation methods and explore a fast disease leaf image segmentation method.

5 Experiments and Results

In a global tresholding algorithm, we use an arbitrary value for the threshold value. Therefore, how do we know that a value we have selected is good or not. The answer is, test method and error [11]. Nevertheless, consider a bimodal image (In simple terms, a bimodal image is an image which histogram has two peaks). For this image, we can roughly take a value in the middle of these peaks as a threshold value, right. This is what Otsu binarization does. Therefore, in simple terms, it automatically calculates a threshold value from the histogram of the image for a bimodal image (For images that are not bimodal, binarization will not be accurate) [11]. The Fig. 4, shows two results obtained as images of a FAW and its eggs (via the Otsu algorithm). To evaluate the proposed algorithm, we define and use two parameters which are Local Consistency Error (LCE) and Processing Time (PT in seconds). The measure of coherence between Martin's segmentations is based on two errors calculated in each pixel: an error of V with respect to R and an error of R with respect to V. If the pixels belongs to the region Vj in the truth-terrainand to the region Ri in the result image, these errors are: E (s) = card (Vj\Ri)/card (Vj) and E′(s) = card (Ri\Vj)/card (Ri). E (s) is 0 if Vj is a subset of Ri and is equal to 1 if the intersection of the two regions is reduced to pixels [11].

The dissimilarity between segmentation result and reference segmentation is then measured by the local error of coherence. The latter is estimated with Eq. 3.

$$LCE(R, V) = \frac{1}{A} \sum_{S} \min\left\{E(s), E^{'}(s)\right\} \tag{3}$$

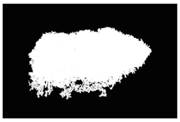
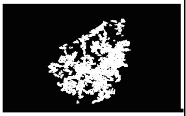
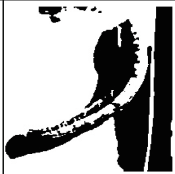
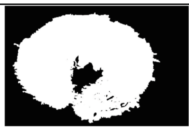
Type of image	Original image	ground truth image	Result	LCE	PT
Eggs 1				5.2726e-06	2
Eggs 2				5.8576e-06	2
larvae				1.6693e-05	1
Adult FAW				3.1335e-06	5

Fig. 4. Results of FAW detection image segmentation.

6 Conclusion

Fall Armyworm is a scourge of agriculture that must be eradicated. The multi-level early detection technique based on the electronic nose offers a better future for ecological control of FAW by avoiding the harmful effects due to the use of pesticides and GMOs. An integrated control method, using the different control techniques at the right time, will ensure efficient agriculture. Based on the results obtained, region based approach technique segmentation method is sensitive to noise but also the starting condition. In our approach, we used the framework of transferable belief function to model the different potential sources of acquisition noise that are taken into account when extracting image features that have been negatively impacted by its noise. Hence the robustness of the proposed technique to be robust against noise. In addition, three different features of the image were extracted and merged into one by exploiting the cautious information combination rules provided by the TBM tool to enhance the sowing performance and power of the segmentation algorithm. So, that our work can be a competing contribution of the NURU application, we deem it necessary to improve it, by:

- The addition of other segmentation techniques such as: region growth, split algorithm and merge and the bubble algorithm.
- Improvement of pre-processing operations (filtering, histogram equalization, etc.).
- Assessment of the infestation level of cornfields.

References

1. Ahouandjinou, A.S.R.M., Kiki, P.M.A.F., Assogba, K.: Smart environment monitoring system by using sensors ultrasonic detection of farm pests. In: 2017 2nd International Conference on Bio-engineering for Smart Technologies (BioSMART), Paris, pp. 1–5 (2017)
2. Ahouandjinou, A.S.R.M., Motamed, C.: Robust Image Segmentation for Early Plant Diseases Detection on Leaf. In: 20ième Colloque CORESA, COmpression et REprésentation des Signaux Audiovisuels, CORESA 2018, Poitiers, France, 14 Novembre (2018)
3. Goergen, G., Kumar, P.L., Sankung, S.B., Togola, A., Tamò, M.: First Report of Outbreaks of the Fall Armyworm Spodoptera frugiperda (J E Smith) (Lepidoptera, Noctuidae), a New Alien Invasive Pest in West and Central Africa. PLoS ONE **11**(10), e0165632 (2016)
4. Fatoretto, J.C., Michel, A.P., Silva Filho, M.C., Silva, N.: Adaptive Potential of Fall Armyworm (Lepidoptera: Noctuidae) Limits Bt Trait Durability in Brazil. J. Integr. Pest Manag. 8(1) (2017)
5. Bateman, M.L., Day, R.K., Luke, B., Edgington, S., Kuhlmann, U., Cock, M.J.W.: Assessment of potential biopesticide options for managing fall armyworm (Spodoptera frugiperda) in Africa. J. Appl. Entomol. **142**(9), 805–819 (2018)
6. Food and Agriculture Organization of the United Nations, Integrated management of the fall armyworm on maize: a guide for farmer field schools in Africa (2018)
7. Midega, C.A.O., Pittchar, J.O., Pickett, J.A., Hailu, G.W., Khan, Z.R.: A climate-adapted push-pull system effectively controls fall armyworm, Spodoptera frugiperda (J E Smith), in maize in East Africa. Crop Prot. **105**, 10–15 (2018)
8. Spodoptera frugiperda (fall armyworm). https://www.cabi.org/isc/datasheet/29810#toPictures
9. http://www.fao.org/news/story/en/item/1141889/icode/
10. Food and A. O. of the United Nations. Integrated management of the Fall Armyworm on maize. Food and Agriculture Organization of the United Nations (2018)
11. Bergounioux, M. (ed.): Introduction au traitement mathématique des images - méthodes déterministes. MA, vol. 76. Springer, Heidelberg (2015). https://doi.org/10.1007/978-3-662-46539-4
12. Thangaduraiand, K., Padmavathi, K.: Computer vision image enhancement for plant leaves disease detection. In: IEEE, World Congress on Computing and Communication Technologies, Trichirappalli, India, pp. 173–174 (2014)