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Develop an acoustic device for red palm weevil early detection

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Abstract
Early detection of the red palm weevils (RPW) is a major challenge in agriculture among all kinds of palm trees due to the nature of the insect and the difficulty to trace its infestation through the life stages associated with the tree life. Many methods have been applied for weevil detection such as X-ray diffraction techniques, fluoroscopy, and ultrasound. This research work aimed to develop a simple acoustic device for the early detection of the red palm weevil infestation; sound sensors and Arduino board were used for the recording process and some Pc programs have been used for extracting the recorded signal features under lab conditions and to evaluate the system in the field. Results under lab conditions indicated that Larva feeding sounds were a very good signature of the early recognition of RPW infestation. Many tests under field conditions were executed to record the sound inside 40 date palm trees once for 8 months, these date palm had not any symptoms of RPW infestation at the beginning, by using the developed system, the results revealed that there were only 8 date palm trees from 40 have not been detected by the system but the infestation appeared later on them with an error of 20% and efficiency 80% of the system. The developed device is a good tool for the early detection of RPW.

Keywords: Red palm weevil, acoustic detection, some morphological specifications of red palm weevil

Introduction

Egypt, Iran, Saudi Arabia, Algeria, Pakistan, and Iraq are the five leading date producers and constitute about 71% of global dates production (FAO, 2014). The annual production of dates in Egypt is 1.55 G Ton from 47.552 M hectares (Annual Bulletin of Statistical Crop & Plant Production, 2018), this record is different now according to the new national project "One Million Date Palm Cultivation" which has been started in the Western desert in the El-Wadi El-Gadid region, Egypt.

The date palm (*Phoenix dactylifera* L.) is considered one of the oldest cultivated fruit in Egypt. Date palm has significant agricultural and socio-economic importance for the Middle East and Egypt. Red palm weevil, (*Rhynchophorus ferrugineus*) is spreading rapidly in Egypt, causing widespread loss of date palm. It spends most of its life deep inside the palm as egg, larva, cocoon, and adult. It causes a destructive effect on the date palm, the main problem is that the grower could not detect the RPW infestation early by the traditional methods such as dog recognition; generally, it is detected only after the palm has been badly damaged. RPW has also been classified as the first category pest in the Middle East by Food and Agriculture Organization of the United Nation (El-Sabea *et al.*, 2009) [5] and (Mukhtar *et al.*, 2011) [12]. Hatching happens in soft places of the tree or after that, the adult puts eggs inside these places and/or in the hard places of the trunk (Hetzroni *et al.*, 2016) [9], the injured places which have been done after harvesting or pruning processes which are main reasons of RPW infestation, the larvae penetrate the palm trunks creating cavities and tunnels that weaken the tree structure by reducing the transfer of water which carries nutrients between the root system and the crown. The hidden larvae usually remain undetected until they cause severe damage inside the trunk. As well as RPW is a strong flier that can cover up to one kilometer in a single flying attempt and up to 7 km in 3-5 days (Abbas *et al.*, 2019) [1]. This characteristic enhances the ability of RPW to disperse, and infests new areas (Murphy and Briscoe, 1999) [13].

All stages of the RPW life cycle could be found in the same tree. The presence of adults is one of the RPW infestation symptoms. Successful pheromone traps of several species of adult palm weevils have been reported to be effective (Ferry and Gomez 2003, Alpizar *et al.*, 2002, and Perez *et al.*, 1994) [7, 3, 15]. Other methods have been investigated to detect the RPW directly and early, ranging from trained dogs to find the RPW (Nakash *et al.*, 2000) [14], neutron activation of cerium-labeled larvae (Rahalkar *et al.*, 1973) [16], and neutron radiography (Alghamdi, 2011) [2], Ultrasound and X-ray-based techniques have also been explored (Tofailli, 2010) [17], to acoustic method with signal processing algorithms (Hussein *et al.*, 2010) [10]. These methods were common in the USA and Europe but until now the main methods in Egypt are using trained dogs and trained workers but after the appearance of RPW infestation.

The acoustic recordings from insects in trees often reveal signals with spectral and temporal features that make them distinctive and easily detectable (Mankin *et al.*, 1995) [11]. Preliminary studies demonstrated that sensitive microphones and dedicated amplifiers enable the detection of the movement and feeding sounds of RPW larvae in palm trees (Hetzroni and Mizrach, 2004) [8]. Hussein *et al.* (2010) [10] reported that Different sounds of the RPW activities could be recorded, including feeding, moving, and spinning sounds of the larva, the cocoon, and the adult. The audio detection system for the RPW feeding sound was presented in detail because it was a clear signature of RPW's existence inside the date palm tree. They recorded larva sound and extracted features that have been used in the system using the Laar WD 60© recording device.

This research work aimed to develop a portable device using new technology components for the early detection of RPW sounds inside the date palm trunk, to help the date palm growers for saving their trees from RPW harmful insect.

Materials and Methods

Lab experiments

Twenty date palms (with 15-30 cm in diameter and 100-150 cm in height) were identified by dog and labor to separate the RPW infested trees (Figure 1) from the others, 15 were infested and 5 were uninfected by RPW. They were transferred to the laboratory for the morphological study and sound recording of RPW larvae and adults. These date palms were brought from Rossetta, El-Boheira Governorate, and EL-Badrasheen, Giza Governorate, in a safe box. The infested palms have been separated in a storage room in the same place of the lab, and then one by one was transported to the lab.

- In preparing the date palm tree, the trunk was divided into small blocks of 50 cm height (1.5 m date palm height divided into 3 pieces), to focus on the weevil development and investigate different activities of the larvae during recording.
- A microscope has been used to study some morphological specifications of the larva and adult and has been connected to PC, for the real understanding of this insect.
- A sound isolation chamber has been used with dimensions of 50cm X 50cm X 100cm, made from wood, and covered by sound isolation sheets from inside to record the sound of RPW activities Figure 2.

Fig 1: The destructive effect of RPW on the infested date palm tree.

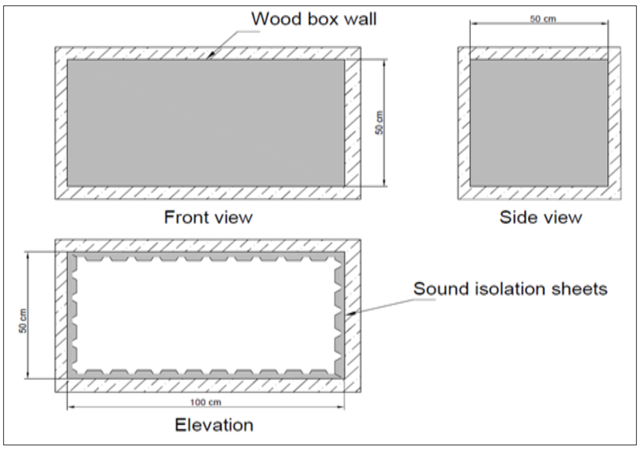


Fig 2: The sound isolation chamber

Developing acoustic recording device and analysis

As the first step of the recording process, an electronic device has been developed, the recording device components were Arduino Mega 2560, and two sound sensors.

Arduino Mega 2560 (Figure 3), is a microcontroller board on the ATmega256. It has 54 digital input/output pins (of which 14 can be used as PWM outputs), 16 analog inputs, 4 UARTs (hardware serial ports), a 16 MHz crystal oscillator, a USB connection, a power jack, an ICSP header, and a reset button. It contains everything needed to support the microcontroller; simply connect it to a computer with a USB cable.

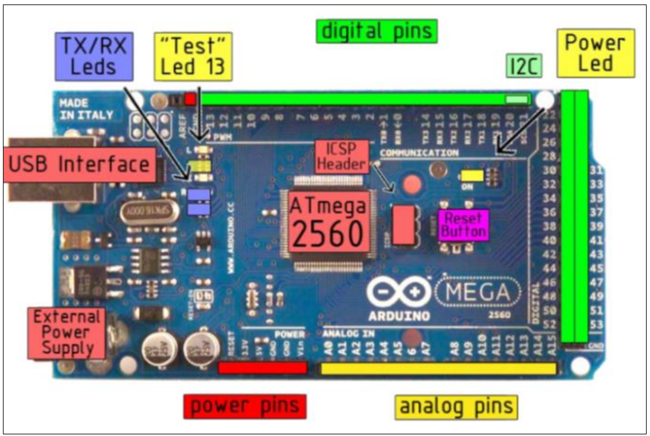


Fig 3: The Arduino Mega 2560 components.

- The sound sensor is an Arduino compatible microphone sound sensor module (Figure 4). It is a high-sensitivity sound detection module with 2 outputs. A0 -analog output, real-time output voltage signal of the microphone. D0 - the digital output depends on the sound intensity and the threshold that has been set.
- The device was connected as shown in Figure 4, where two sound sensors have been used, one Arduino Mega 2560, and connected to a PC via USB, to get the recorded data from the source and store it as a *.wav file.

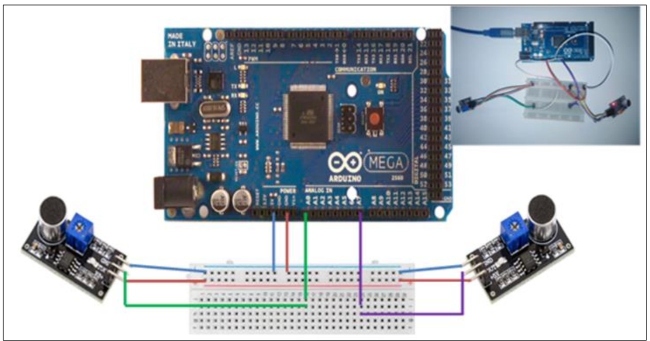


Fig 4: Two high-sensitive sound sensors have been connected to Arduino.

- As reported by Hussein *et al.* (2010) [10], larva feeding sound was a very good signature for red palm weevil infestation in date palm, so larvae have been found inside many cuts of the tested palm trees and the two microphones have been fixed beside the larva to record the feeding sounds, after putting the tree cut inside the isolated chamber (Figure 5).

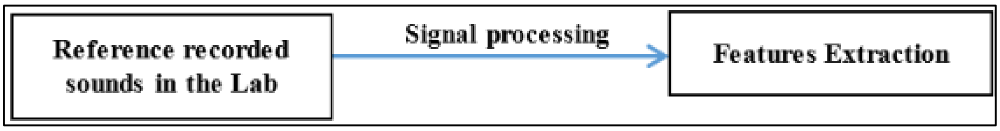
Fig 5: Larva inside the cut of the date palm tree

- The recorded signals from Arduino have been saved as a wave file.
- Then this datasheet has been transformed to a *.wav file at a 44100 Hz sampling rate using Matlab.
- The recorded files were played on a digital audio editing and sound utilization software (Audacity program), for headphone ear recognition, to separate the sound of activity larva inside the cut trunk by experienced workers.
- The recognized sounds (606 sound files, for different 100 larvae of almost the same age), for a period of 8 months, the feeding sound was the most recognized one, with 1 min time length, other activities such as spinning and moving, were not clear as feeding sound.

Signal processing

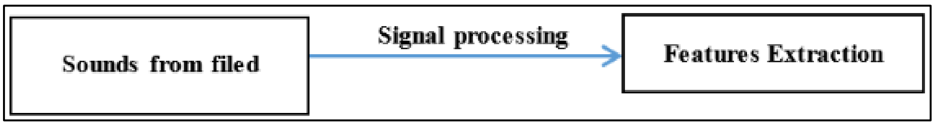
Using MATLAB, The recordings were digitized at a 44100 Hz sampling rate and then a high-pass filter was applied with a cutoff frequency of 0.25 kHz to eliminate low-frequency background noise.

Domain features were extracted for each time frame to have a time distribution of the features along the recorded signal, for extracting the spectral domain features, each time frame was scaled by a suitable window function using the Hanning window function (Hussein et al., 2009) and then transformed to the frequency domain using Fast Fourier Transform (FFT) method.



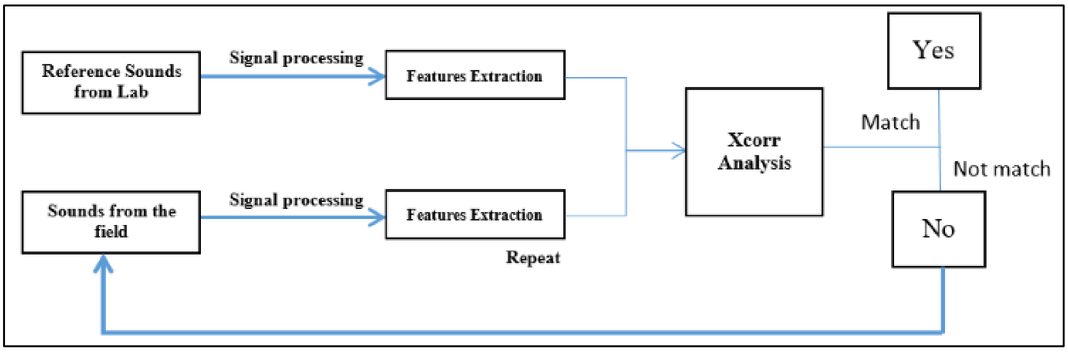
Field experiments

The same recording procedures of 40 date palm trees have been done monthly for 8 months, and 30 had not any symptoms of infestation, to have 320 recording sounds for 1 min long, the same procedures have been executed on the recorded sound files as done in the Lab.



Statistical analysis

Correlation analysis has been measured to compare the recorded frequency spectrum between the referenced sounds (recorded and analyzed in Lab) and the recorded sounds in the field to detect if the date palm is infested or not (Flow chart 1).



Flow Chart 1: The stages for detecting the RPW sound from the recording to the detection.

- Modifying the multifunction date palm machine to control and reduce the RPW infestation.

Results and Discussion

Some morphology specifications of RPW larva and adult

In the lab, some morphological specifications of larvae and adults have been studied, as illustrated in Table 1, the head size of the female adult was greater than the male adult (Figure 6). The same trend has been noticed for the distance between the tip of the rostrum to the antennal insertion. Meanwhile larva body and head were big ranging from 15 mm to 40 mm, from 7mm to 15 mm, respectively. Logically the big size of larvae 4 weeks age is so destructive compared with the medium size of it (Table, 1).

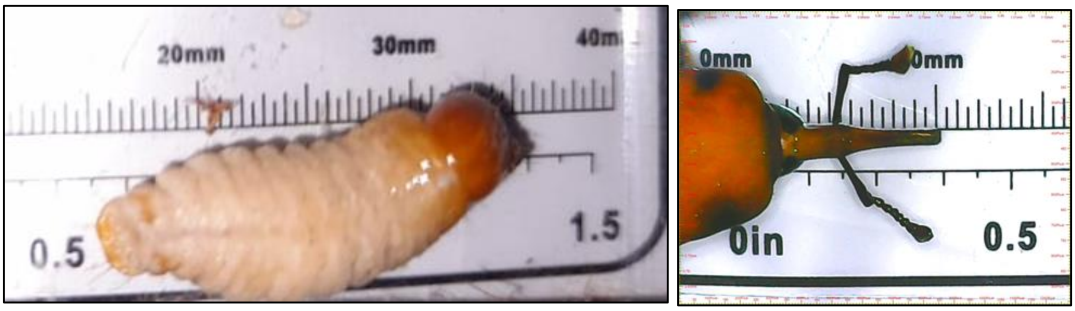


Figure 6: The medium Larva and the female adult under 1000X microscope

Table 1: Some morphological specifications of RPW larva and adult as an average of 20 of each

Adult	**Head size, mm**			**Distance between the tip of rostrum the to the antennal insertion, mm**		
	Min	**Max**	**average**	**Min**	**Max**	**average**
Female	18.60	10.55	14.57	4.80	10.00	7.40
Male	16.00	8.70	12.35	3.40	9.10	6.25
Larva	**Body size, mm**			**Head size, mm**		
	Min	**Max**	**average**	**Min**	**Max**	**average**
Medium size	15.20	22.70	18.95	7.10	9.80	8.45
Big Size	20.20	40.00	30.10	10.00	15.10	12.55

Recording feeding sounds of RPW larvae in Lab and Field

Checking the recording device

The device was connected to PC and checked using the GUI of Arduino, the code was developed to read the getting data from the sound sensor (Figure 7), on the serial plotter monitor as shown in Figure 8.

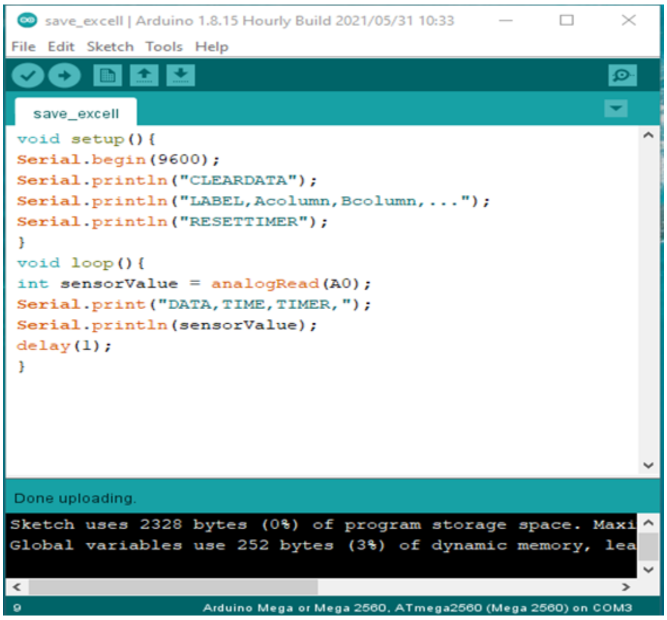


Fig 7: Arduino code for recording using sound sensors

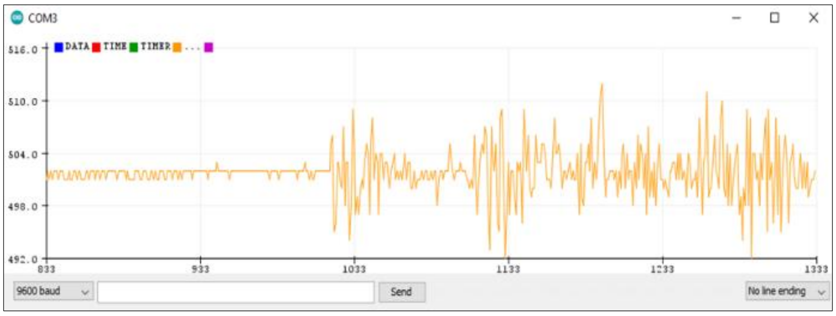


Fig 8: Arduino serial plotter showing the recorded sound spectrum

Connecting the device with Matlab

A licensed version of Matlab (2019b) was used to convert the recorded excel file to wave file to matlab.mat file.

Coding in Matlab for audio files reading and analyses

Developed code in Matlab was used to read and extract features of all RPW feeding sounds. The results of the developed code have been documented as in Figure 11 to extract the features of each recorded file.

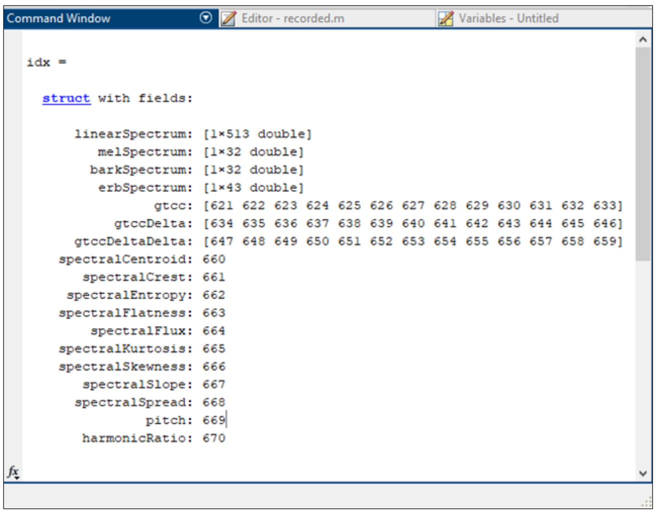


Fig 11: Extracted features of the recorded feeding sounds

More than 606 recording attempts have been done, 1 min long under the lab tests, as well as 106 files have been extracted of larva feeding sound and saved in the length of 1.2s as shown in Figures from 12 to 16 which clarify the oscillogram, spectrum, spectrogram, pitch, some features of the recorded signal, respectively.

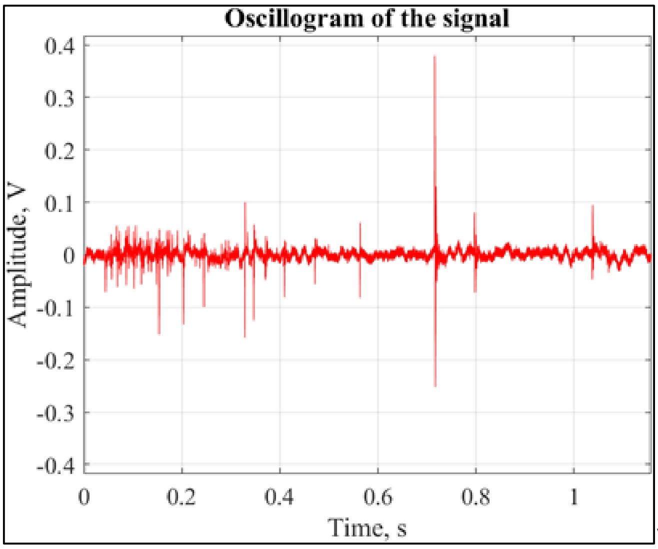


Fig 12: Oscillogram of the signal

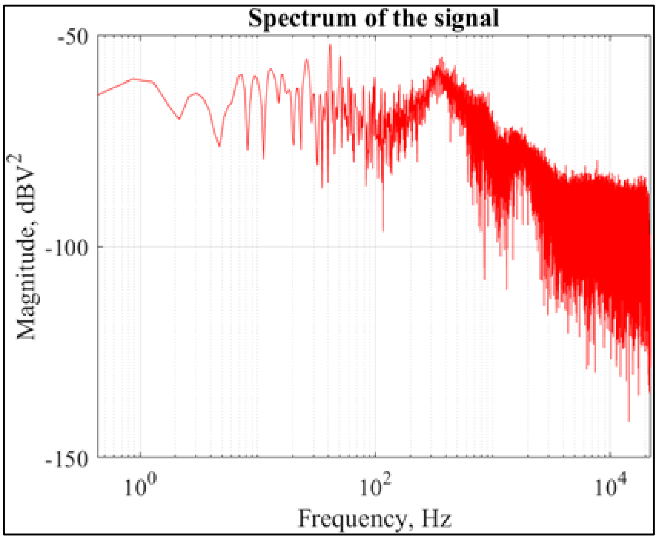


Fig 13: Spectrum of the signal

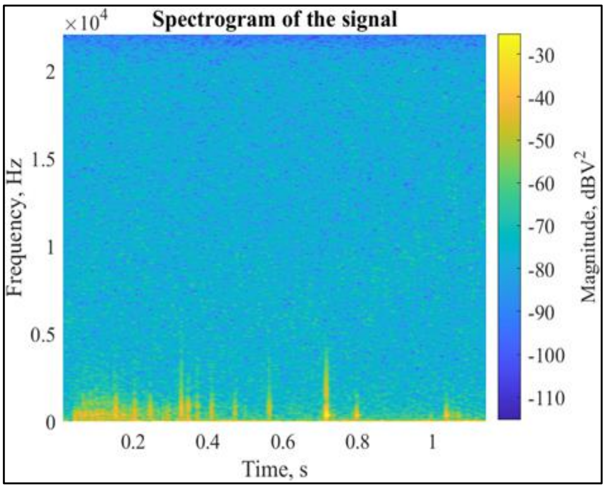


Fig 14: Spectrogram of the signal

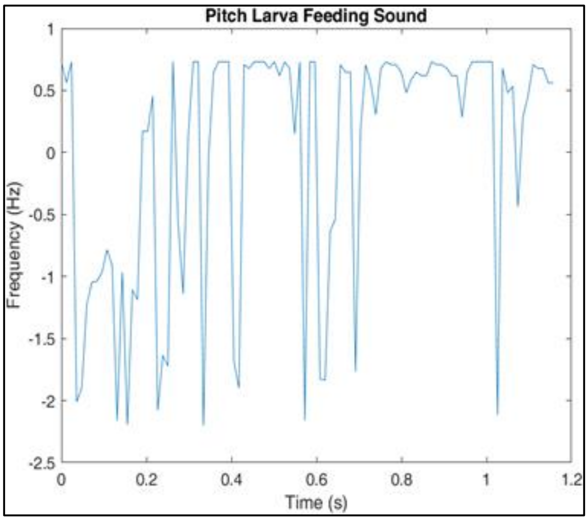


Fig 15: Pitch of the signal

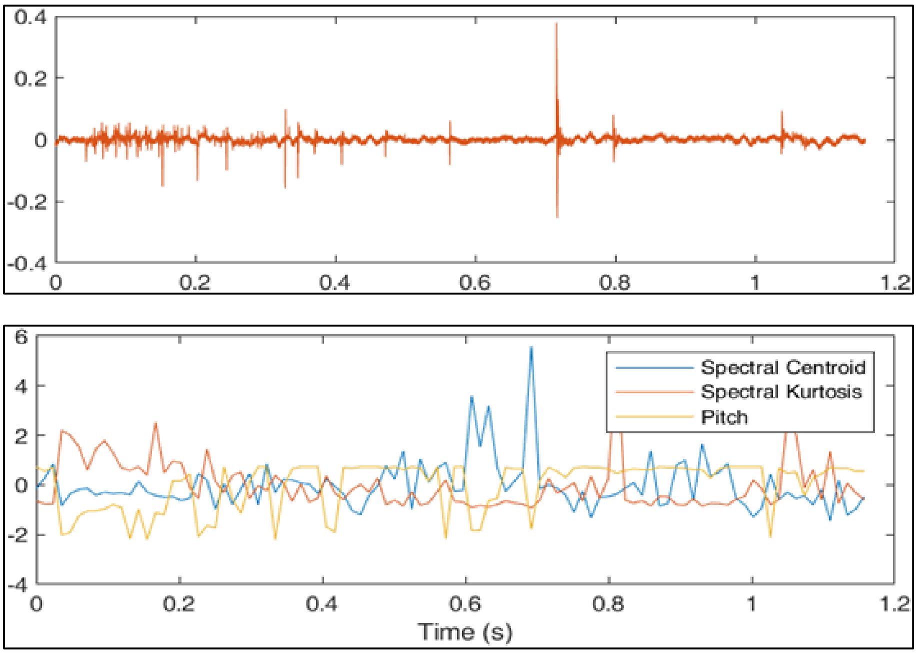


Fig 16: Some features of the signal

Validation of the system

106 sounds were extracted from 606 feeding recordings, these sounds were used for the validation of the developed device and generally the developed system to extract the features of the signal for each recording using the features extraction Matlab code, then compared the extracted signal features, using xcorrelation code in Matlab.

Fig. (17) shows an example of the match between 106 recorded files features and the main extracted features of the RPW feeding sound. 91 records were well defined as a feeding sound of red palm weevil, and on the other hand, 15 records were not detected, which means the system efficiency was 85% to detect the RPW infestation.

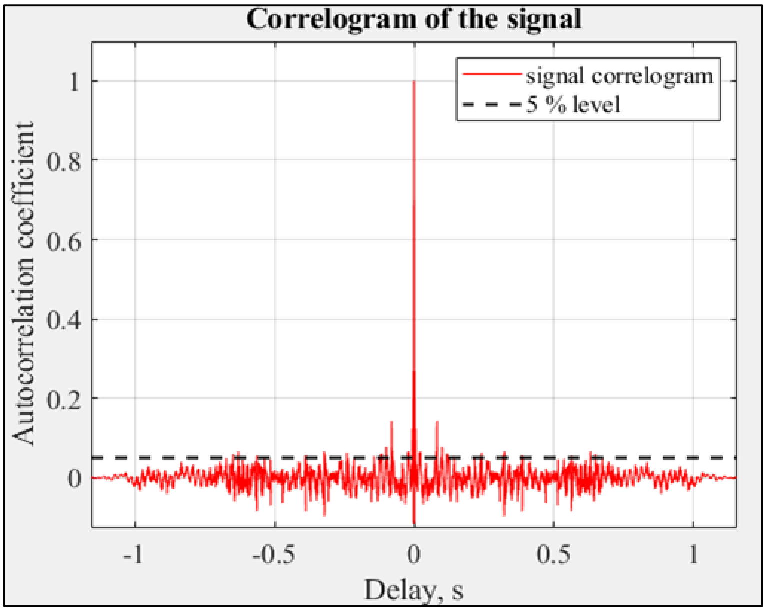


Fig 17: Match between two audio files at 5% level

Evaluation in the field

Many sounds have been recorded in some date palm field since October 2020, Rosseta, El-Buheira El-Giza Governorate, and El-Badrasheen, El-Giza Governorate, on 40 date palms, that have not any symptoms of RPW exist. Results of the recording of infested trees, give 100% matching with the pre-recorded RPW feeding sounds. Every month a recording has been done for the 40 trees in the field, Table 2 shows the periodical detection every month for RPW infestation until some clear symptoms appeared then the recording has been stopped. The tests of RPW for the 40 date palms, were good tests of the developed system. The not detected trees by the system but the infestation appeared later for 8 trees only from 40 trees with 20% error, or 80% detection efficiency. Furthermore, there were 4 recordings only were not appear any feeding sounds of the larvae after the detection in the previous month such as with trees No. 14, 25, and 37, this was due to the trees being infected but no larvae inside, or they had few numbers of Larvae, or there no feeding sounds from larva inside the tree during the recording time.

Table 2: The recording schedule for 40 date palms in the field.

Tree No.	Month							
	Oct., 2020	Nov., 2020	Dec., 2020	Jan., 2021	Feb., 2021	March, 2021	Apr., 2021	May., 2021
1	N	N	N	N	N	N	N	N
2	N	N	N	N	N	D	D	D + H
3	N	N	N	N	N	N	N	N
4	N	N	N	N	N	N	H	H
5	N	N	D	D	D + H	S	S	S
6	N	N	N	N	N	N	N	N
7	N	N	N	N	N	N	N	N
8	N	N	N	N	N	N	N	N
9	N	N	N	N	N	N	N	N
10	N	N	N	N	H	H	H	H
11	N	N	N	N	N	N	N	N
12	N	N	N	N	N	H	H	H
13	N	N	N	N	D	D	D + H	S
14	D	D	D + H	D + H	D + H	D + H	D + H	D + H
15	N	N	N	N	N	N	N	N
16	N	N	N	N	H	H	H	H
17	N	N	N	H	H	H	H	H
18	N	N	N	N + H	N + H	N + H	N + H	N + H
19	N	N	N	N	N	N	N	N
20	N	N	N	N	D + H	S	S	S
21	N	N	N	N	N	N	N	N
22	N	N	D	D	D + H	S	S	S
23	N	N	D	D	D + H	S	S	S
24	N	N	D	D	D + H	S	S	S

25	N	D	D + H	D + H	S	S	S	S
26	N	N	N	N	N	N	N	N
27	N	N	N	N	H	H	H	H
28	N	N	N	N	N	N	N	N
29	D	D	D + H	S	S	S	S	S
30	N	N	N	N	N	N	N	N
31	N	N	N	N	N	N	N	N
32	N	N	N	N	N	N	H	H
33	N	N	N	N	N	N	N	N
34	N	N	N	N	N	H	H	H
35	N	N	N	N	H	H	H	H
36	N	N	N	N	D	D + H	S	S
37	N	N	D	D	D + H	D + H	S	S
38	N	N	N	N	N	N	N	N
39	N	N	N	N	N	N	N	N
40	N	N	N	N	D + H	S	S	S

* N = Not detected, H = Human detection, D = Detected by the developed acoustic device, and S = Stop recording.

Final product

A device for the acoustic detection of the Red Palm Weevil has been manufactured and well tested in the field. This device could be connected to the PC, to do recording, replay the recorded sounds and finally analyze the recorded voices in the field and give the last decision if the palm is infected or not.

Conclusion

Early detection of the red palm weevils (RPW) is a major challenge in agriculture among all kinds of palm trees due to the nature of the insect and the difficulty to trace them through their life stages associated with the tree life. Therefore this work aimed to develop a simple acoustic device for the early detection of the red palm weevil infestation; sound sensors and Arduino board were used for the recording process and some Pc programs have been used for extracting the recorded signal features under lab conditions and to evaluate the system in the field. After a long study and many trials, the recording device and the detection system was developed using sound sensors and Arduino to be connected with the Pc via the Matlab program. The developed recording system and device have been developed, manufactured, and well tested for early detection of the RPW's existence. The detection process was easy and available for the farmers with a very high percent of detection (80%).

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