Acoustic Detection Possibility of Different Stages of the Confused Flour Beetle (*Triboium confusum*) in Grain Bulks Using an Audio Sensor

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ABSTRACT

Recent advances in computer technology as well as in signal processing and pattern recognition, provide the possibility of automatic identification of pests, based on their audio signals. In this research a sound reinforced piezoelectric sensor along with a detection circuit based on a database was designed in order to receive audio signals with intensity lower than human hearing limit (zero dB). The confused flour beetle, *Triboium confusum* was used in this experiment. The signals received from larvae, adult and the combination of these two stages, in wheat grain bulk at three distances of 10, 20 and 30 cm from acoustic sensors were investigated. In each experimental run the characteristics of signals frequency including range, time, amplitude and intensity were extracted. For all three distances the sound produced by the larvae had a peak intensity in the frequency range of 2.4 kHz (for feeding) and the adult insect's sound had two peaks intensity in the frequency range of 2 kHz (for feeding) and 2.3 kHz (for walking). The differences between the frequency characteristics of sound produced at different stages might provide the possibility of identifying the life stages of the pest, pest distance to the sensor and approximate location of the pest. Based on these findings, the sound sensor and the audio circuit were designed to detect larvae, adult, or both at a distance of 30 cm. Further investigation is continuing to improve the audio system programming and the related circuits for more accurate detection of the pest.

Keywords: Acoustic, Insect, Sensor, Stored product, *Triboium confusum*.

INTRODUCTION

Many different species of insects have been identified, some are beneficial and many are harmful. Harmful insects or pests, particularly in agricultural products cause considerable losses annually. In many developing countries, the overall postharvest losses of cereals and legumes are about 10-15% (Brooks and and Fiedler 2007). Pest infestations in stored grain and consuming cereals by pests such as insects and contamination by microbial spoilage may make them totally inedible. The presence of live insects in many commercial grains is prohibited. However, current standards for international trade of grain only consider visible live foreign organisms (ISO, 1986). On farms, manual samples, traps and probes have been used to determine the presence of insects (Neethirajan *et al.,* 2007). Manual inspection, sieving, cracking-floatation and

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Berlese funnels are being used at present to detect insects in grain handling facilities. These methods are not efficient and are time consuming. Acoustic detection, carbon dioxide measurement, uric acid measurement, near-infrared spectroscopy, and soft X-ray method have the potential to be used at the industry level to detect insects in grain samples as their usefulness has been demonstrated in the research laboratories (Neethirajan *et al.,* 2007). Therefore the use of these methods for detection of such living organisms hidden inside the kernels, before appearance, is almost impossible. In other words, with the current detection methods the true population of the pest inside the grain bulk may be much more than what has been seen. Therefore the early detection of hidden insects in grain storages is a major problem.

The developments in computer industry, electronic systems and signal processing technology are drastically growing. These advances can provide a proper base for research and development in automatic detection as well as identification of insect pests within a grain bulk through audio signals (Chesmore, 2001; Dietrich, 2004) and image processing. In recent years some researches have been carried out on acoustic detection of insects (Schwab and Degoul, 2005; Mankin *et al.,* 2011; Herrick and Mankin, 2012), but they are still in their early stages.

In pest control and their eradication process, the problem of identification and early detection is crucial. With regard to the recent hardware and software developments in the field of audio signals, it might be possible to detect the pests through their voice recognition. Audio identification of insects using their ability to produce sound as a means of communication or as a result of their walking or feeding activities can be used as a means of pest detection, as long as the audio signal generated from a certain insect follows a unique acoustic pattern and compatible with certain species (Potamitis and Ganchev, 2006).

Audio frequency detection of insects from surroundings' noise is a difficult task, mainly due to low amplitude of their noise. Various methods and techniques have been used to distinguish the sounds of insects taken from the surroundings. The earliest and simplest method used two microphones for voice recognition of a certain fruit fly. In this approach one of the microphones received the combination of the insect sound and the surroundings' noise and the other microphone received only ambient noise, simultaneously. With the subtraction of these two received sounds, the audio frequency of the insect was determined (Neethirajan *et al.,* 2007).

Some insects, produce the sound of humming or singing of virgin. In a study to identify the crickets, stick insects and grasshoppers, the sounds produced by different species were acquired and recorded. The received voices were classified in various categories, families, subfamilies, genera and species. The accuracy of sound identification in the family level and species level were up to 98 and 86%, respectively (Ganchev *et al.,* 2007).

Among the methods of pest detection and control pollution of stored grain, voice recognition method seems to be a promising tool and over the past two decades has been examined for pest detection inside the stored grain. However, the results of most of these researches are fairly poor (Fleurat-Lessard *et al.,* 1994; Brooks and Fiedler, 2007; Hagstrum *et al.,* 1996). The main reason for the weakness of results is related to the lack of or the use of proper audio sensor. Due to very low intensity of the sounds produced by pests, the use of conventional sensors is not suitable for such condition. Therefore an amplification circuit or other enhancement is required to overcome this limitation.

Insects' activities in grain mass produce noise in the audible wavelength range, but can be detected only by acoustic sensors with high performance (Fleurat-Lessard *et al.,* 2006). Such a work was reported by (Fleurat-Lessard *et al.*2006). using a

portable probe length of 4.1 meters, having several acoustic sensors with a certain distance inside and the audio signals from rice weevil and cereals beetles have been studied. The acoustic device could receive the sound of the pest from a distance up to 20 cm. The sensor was capable of detecting the pest density of 1 per 10 kg of grain at temperatures above 10°C (Fleurat-Lessard *et al.,* 2006).

Adult and immature stages of stored product insect pests vary considerably in size and in the amplitudes and rates of sounds they produce (Mankin *et al.,* 1997).

Considering the characteristics of adult insect audio frequencies, at different distances can be long-term goals in helping to design the layout of acoustic sensors array, the number and the location of sensors inside the stored grain bulk for the proper detection of the pest.

MATERIALS AND METHODS

Acoustic Equipment Design

The sensor used to record the pest's sound is a piezoelectric type with an appropriate modification in order to detect the low intensity sounds such as pest's sound. The sensor was equipped with a very strong boost circuit for pre-amplification of sounds which is crucial for receiving very low acoustic sound intensities, and becoming audible sounds. The amplifier circuit has been built in such a way that it is possible to connect a PC and hence stores audio signals, and also eliminates surrounding noises. Profile acoustic sensor includes: Piezoelectric microphone, power with battery 12V (maximum consumption of 50 mA), two class amplifier series (first floor of a transistor and second floor of an op amp) and output audio jack connectable to the computer system and speaker. The pest sounds can then be recognized through its built in database. The main data storage and other data analysis are performed through a program written in MATLAB software (Figure 1). The laboratory chamber was a small scale soundproof room with a constant temperature of about 20 °C . To minimize the income noise and hence efficient noise removal process, the chamber was built from a special three-layer glass. The pests and grain were placed inside a cylinder made of PVC with 10 mm diameter and 50 cm height. During data collection (sound recording) the cylinder was placed inside the soundproof chamber (Figures 2 and 3). The designed circuit was activated by a 9-volt battery, which can power the circuit for at least 7 hours.

Experimental Procedure

Study Insect

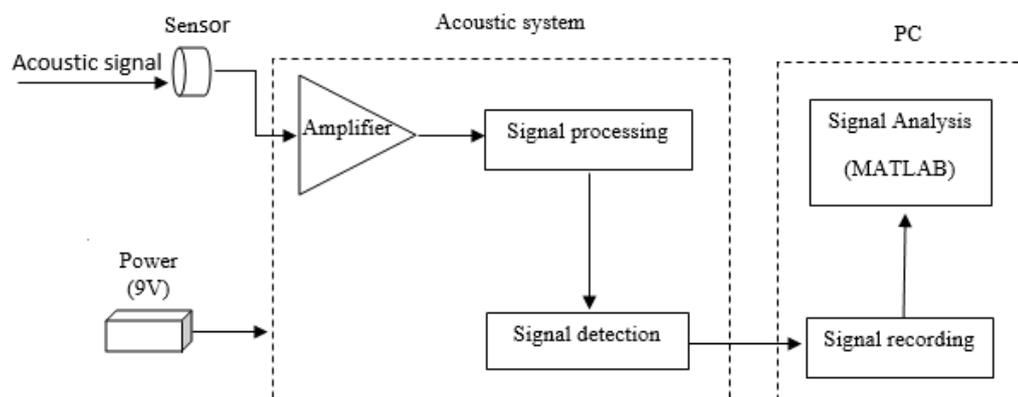The study insect pest was the confused

Figure 1. Flow diagram for acoustic signal detection and signal analysis of insect pests within a grain bulk.
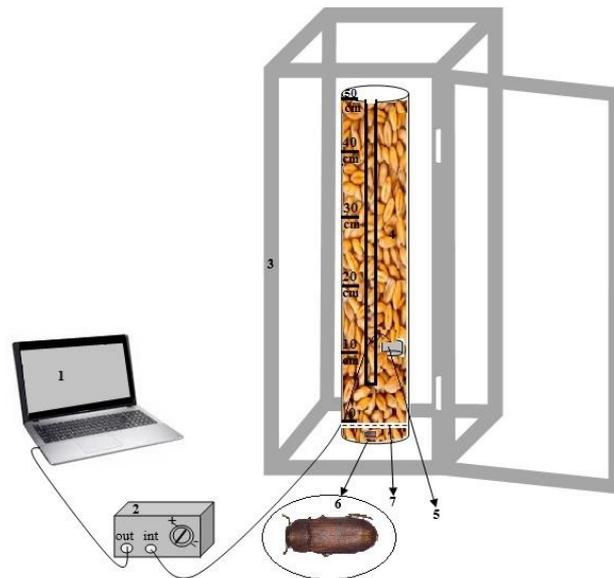
Figure 2. The soundproof test rig including: (1) PC; (2) Integrated signal detection and processing; (3) Acoustic insulation chamber; (4) Grain cylindrical graded repository; (5) Acoustic sensor; (60 *Triboium confusum*, (7) Thin grid.
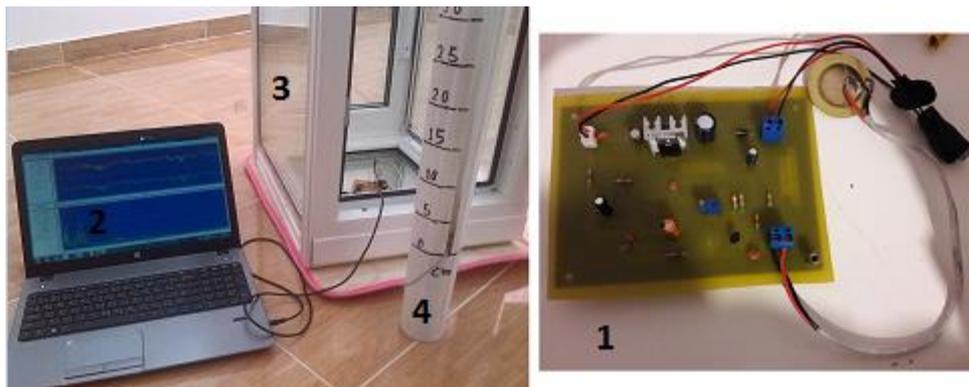

Figure 3. The laboratory equipment: (1) Integrated signal receive and amplify (acoustic sensor); (2.) PC; (3) Acoustic insulation chamber, (4) Graded container.

flour beetle (*Triboium confusum*) which is the most abundant and injurious insect pest of flour mills in many parts of the world.

Acoustic Apparatus

Experiments were performed to record the sound of larvae, adult and the combination of these two stages, from three different distances of 10, 20 and 30 cm. In each run, 5 insects (larvae or adults) of the pest were placed inside the grain container.

Pest recognition inside the grain bulk requires signal detection and noise removal by the audio circuit for the frequencies of the pest in its different life stages including larval and adult. To eliminate the noise and acquire the pure frequency of the pest, the frequency subtraction method was used. To perform this technique, two acoustic sensors were simultaneously used. One of the sensors records the sounds of insects and the surroundings, and the other only records the surroundings' noise. The former sensor is directly placed inside the grain bulk

containing the insect and the latter outside the grain container and inside the experimental rig. After the subtraction of these two recordings, the audio frequency of insects is determined through a sound analysis procedure (Neethirajan *et al.,* 2007). The grain dish is of a glass cylindrical with a diameter of 5 and a height of 10 cm. In order to discriminate the sound of the insect at different stages, this procedure was individually carried out for the gain bulk containing the larvae and the adult insect. The recorded sounds were then transferred to a computer via an amplifier circuit and were stored by the recording software. At this step the subtraction method was applied using MATLAB software, for further analysis. The processed signals which were the sound signals of the pests were extracted and stored as the database processing circuit which was an integrated section of the acoustic circuit.

Different distinguished sounds of flour beetles were produced through a series of experiments and based on the previous studies (Fleurat-Lessard *et al.*, 2006), usually occurs in three forms: (1) The feeding sound of larvae. The larva usually penetrates into the kernel of grain and starts eating the inside of the grain, this activity generates the feeding or eating sound. (2) The walking sound of the adult insect among the grains of the bulk materials. (3) The feeding sound of the adult. The eating activity of adult insect within the grain mass occurs by scraping the seeds' shell, and generating a unique sound.

The grain used in this experiment was wheat with 13% moisture content. To have enough number of adult and larvae, the insect proliferation was performed inside a small dish of wheat seed. To have the least external noise during experiment, the tests were performed from midnight (12 pm) to 6 am. For adaptation of insect to the test environment, the day before the test, a few numbers of adult insects were put inside the test tube with a thin layer of wheat

grain. Before starting the test, the test tube was filled with pest free wheat grain to a height of 10 cm. To prevent insects from moving to the upper layers, a very thin veil was placed inside the test tube, before filling with wheat grain. The experiments started by putting the sensor directly on the grain bulk surface, a distance of 10 cm from the insects. The sounds of adult insects were recorded and transferred to the computer and the integrated signal processing circuit, for 30 minutes. The sound saving software saves the receiving sounds as some 30-seconds files. The same procedures were performed to record the adults' sounds at distances of 20 and 30 cm, by placing two additional sound sensors at their corresponding height from insects.

To record the sound of larvae, a number of wheat grains with larvae inside, were put on top of a thin layer of wheat grain in the test tube. In the first step, the test tube was filled with wheat grain to a distance of 10 cm (no need to use separator veil, because the larvae is inside the kernel without any movement). For the other two stages of testing, the tube was filled to a distance of 20 cm, and 30 cm, respectively. Audio recordings were performed by placing the sound sensors at their corresponding height (10, 20 and 30 cm) from larvae. The sounds were recorded for 30 minutes, as 60 sound files each of 30 seconds (sixty 30-second files).

In the third stage of testing, the test tube was filled with a thin layer of infested wheat, having several flour beetles (both larvae and adult stages) and after inserting the separator veil it was filled with insect-free wheat grain layers of 10, 20 and 30 cm, respectively. The sound sensors were also inserted at their corresponding heights. The sound recordings were performed as the same previous procedures. In all experiments with the help of a temperature control system, the temperature inside the test rig was controlled at about 20°C.

Table 1. The acoustic characteristics of *Triboium confusum* in the larval stage at different distances.

Distance from sensor (cm)	Duration (ms)		Amplitude (mv)		Sound level (dB)		Frequency range (kHz)
	Min	Max	Min	Max	Min	Max	
10	42	54	-0.9 to 0.9	-1 to 1	-26	-22	1.7-2.7
20	25	31	-0.7 to 0.7	-1 to 1	-31	-27	1.7-2.7
30	16	21	-0.5 to 0.4	-1 to 0.8	-38	-35	1.7-2.7

MATLAB software was used to analysis the recorded audio signals and their frequency characteristics were determined.

RESULTS

Acoustic Frequency of Larvae

In larval stage tests, for each of the three individual distances (the distance between the larvae and sensor), 60 stored audio frequencies were analyzed (totally 30 min sound recording) using MATLAB software. Due to instantaneous activity of several larvae, some of the recorded sounds had several sound pressure peaks. During the full activity, approximately every 10 milliseconds the larvae generate a sound. Figure 4 shows a sample of the audio signal produced by the larvae in the time domain and its peak intensity in the frequency domain. In general, the sound frequency of feeding (as the only activity of larvae) is observed in the range of 1.7 to 2.7 kHz, and its peak intensity occurred at about 2.4 kHz. This range of frequency is almost concurrent with the frequency range of human hearing. But, since the minimum hearing dB level of human healthy ear is zero and the dB level of larvae feed frequency is always negative and quite below the zero, therefore the feeding sound of larvae is not an audible voice for human.

It is seen that with increasing the distance between sensor and larvae, the frequency range of the produced sound is remained unchanged. However, the sound features such as amplitude, time and the intensity of incoming audio signal decreases. Table 1 shows the frequency characteristics of the saved audio signal of larvae for the three individual distances (during 30 minutes recording). The durations of audio frequency of larva ranged between 42-54, 25-31 and 16-21 milliseconds, for distances of 10, 20 and 30 cm, respectively. Among the three distances, the changes in amplitude were far less than other characteristics such as time (duration) and the sound intensity level. For the distances of 10, 20 and 30 cm, at the peak frequency, the sound pressure level ranged between minus 22-26, 27-31 and 35-38 dB, respectively. These results demonstrate that the employed acoustic sensor and the integrated amplification circuit can effectively sense and record the sound of *Triboium confusum* larvae from a distance of 30 cm inside wheat grain bulk. Moreover, due to the differences between the sound frequency characteristics of larvae at different distances, it is also possible to estimate the larvae distance from the sensor, considering these differences.

Acoustic Frequency of the Adult Stage

During the experiments with adults of flour beetle, for each of the three individual distances between the insect and sensor, the sounds were also recorded for 30 minutes and were analyzed as 60 stored audio frequency files. The adult insect of confused flour beetle in the grain mass has two activities and hence has two frequency ranges, one for walking and the other for feeding. So the frequency of the adult insect has two ranges of frequency with their own characteristics. Due to high mobility of the
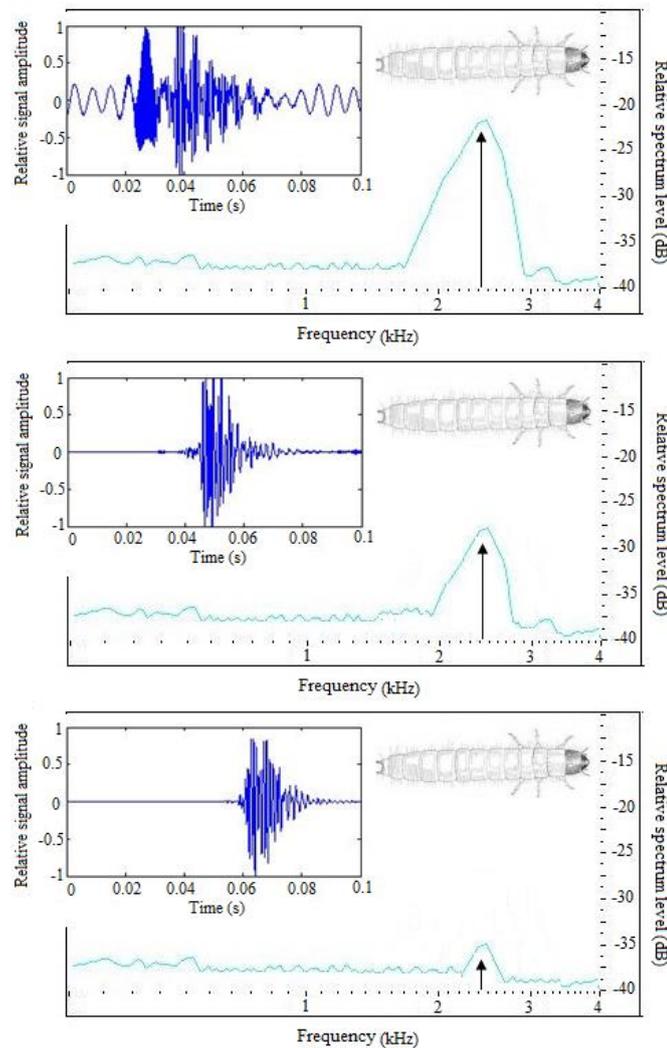
Figure 4. The acoustic characteristics of *Triboium confusum* in the larval stage, recorded within wheat grain mass at different distances of larvae and audio sensor (from top to bottom 10, 20 and 30 cm, respectively).

insects within grain bulk, their audio frequencies may be frequently produced at any time. Figure 5 shows samples of audio signals produced by the adult insects in the time domain and also the peak intensity level in the frequency domain. As mentioned, due to two different activities of the adult, it is seen that the adult insect audio frequency has two ranges: about 1.3-3 kHz (for eating) and 1.9-3 kHz (for walking). The adult insect's sound had two peaks intensity in the frequency range of 2 kHz (for feeding) and 2.3 kHz (for walking). The

frequency of walking has lower peak intensity than the eating frequency. Moreover, by comparing Figures 3 and 4, it is seen that the pattern and shape of the frequency signals of the adult insect and the larvae are clearly different, and hence these differences can be used to discriminate the adults from larvae.

The same as larvae, it is seen that with increasing the distance between sensor and insect, the frequency ranges of the produced sounds are almost remained unchanged. However, the sounds features such as

amplitude, time and the intensity of incoming audio signals decreases (Figure 5). Table 2 shows the frequency characteristics of the saved audio signal of insect for three determined intervals (each 30 minutes), with a single audio frequency length of adult insect for the three individual distances (for 30 min sound recording). The durations of walking and eating sounds of adult for the distance of 10 cm ranged between 25-30 and 44-58 milliseconds, respectively. The corresponding durations for the distance of 20 cm ranged between 15-23 and 27-33 milliseconds and for distance of 30 cm
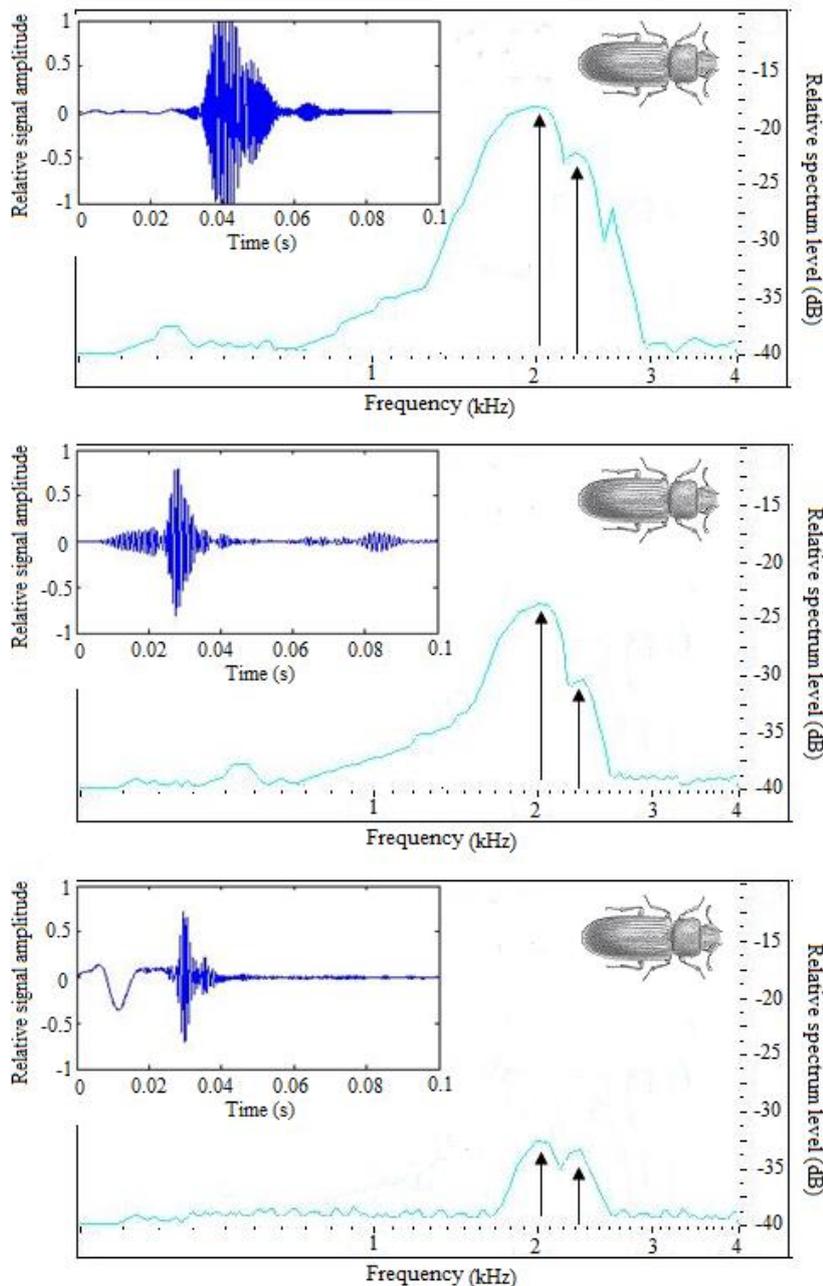

Figure 5. The acoustic characteristics of the adult insect of *Triboium confusum* recorded within wheat grain mass at different distances of insect and audio sensor (from top to bottom 10, 20 and 30 cm, respectively).

Table 2. The acoustic frequency characteristics of *Triboium confusum* (adult) at different distances.

Distance from sensor (cm)		Duration (ms)		Amplitude (mv)		Sound level (dB)		Frequency range (kHz)
		Min	Max	Min	Max	Min	Max	
Walkin	10	25	30	-0.8 to 0.8	-1 to 1	-28	-23	1.9-3
	20	15	23	-0.4 to 0.4	-0.7 to 0.7	-35	-30	1.9-3
	30	10	14	-0.1 to 0.1	-0.2 to 0.2	-39	-34	1.9-3
Feeding	10	44	58	-0.1 to 0.9	-1 to 1	-21	-18	1.3-3
	20	27	33	-0.9 to 0.8	-1 to -1	-26	-24	1.3-3
	30	18	24	-0.5 to 0.5	-0.7 to 0.7	-37	-33	1.3-3

ranged between 14-10 and 18-24 milliseconds, respectively. Moreover, the differences between walking signal amplitudes of distances are significant and hence can be used to estimate the distance between the insect and sensor. Also the amplitudes of audio signals of walking are much lower than the eating and hence can be used to identify the type adult activity, if needed. At the peak frequency, the sound pressure level intensity ranged between minus 28-23 and 21-18 dB at a distance of 10 cm for walking and feeding, respectively. The corresponding characteristics at distance of 20 cm ranged between 30-35 and 24-26 dB and at distance of 30 cm ranged between 39-34 and 37-33 dB. These results provide the feasibility of estimating the distance between insect and sensor and hence the location of insect within grain bulk can be identified. The comparison of Figures 3 and 4 indicates that the audio frequency characteristics of larvae and adult insect are also significantly different and hence can be used to distinguish larvae from adult insect. Moreover, the adult insect of the flour beetle can be detected at a distance of 30 cm from its audio signal of either walking or feeding.

Acoustic Frequency Gained From Wheat Grain Mass Infected With *Triboium Confusum* (Larvae and Adults)

To evaluate the system, a mass of wheat grain was contaminated by several individuals of both larvae and adults of *Triboium confusum*. The sounds coming from inside the contaminated particulate materials were saved for 30 min as 60 individual audio files and were then analyzed. The results are presented in Figure 6. As the infected grain mass has a large number of pests (including larvae and adults) in the acquired audio frequency several sound intensity peaks are observed in the range of 1.3-3.3 kHz. This is mainly due to different simultaneous activities of the pests (eating of adults and larvae and walking of adults). The peak intensity of sound is observed at frequency of 2 kHz, which is probably associated with scratching of the grain's shell by adult insects. Moreover, the shape and pattern of these audio signals is different from the two previous tests (with individual larvae or adults) which is due to accumulated, continuous and simultaneous activities of many larvae and adults within the grain mass.

The results of audio frequency analysis for all three distances are separately listed in Table 3. In term of frequency range, the recorded sounds correspond to the frequency of previous tests. This implies good performance of the integrated sound recording and processing circuit regarding noise filtering. Furthermore, the duration of sound and intensity level of the frequency in comparison with the previous experiments remain almost unchanged. But some changes can be seen in the frequency range compared with the ranges of previous tests, mainly because of simultaneous activities of several individuals of the flour beetle. Considering these results, the proposed sound recording circuit has the ability of

Table 3. The acoustic frequency characteristics of *Triboium confusum* (larvae and adult) recorded from infected mass of wheat grain at different distances.

| Distance from sensor (cm)		Duration (ms)		Amplitude (mv)		Sound level (dB)		Frequency range (kHz)
		Min	Max	Min	Max	Min	Max	
Walking (Adult)	10	25	29	-0.7 to 0.7	-1 to 1	-29	-23	1.9-3
	20	14	23	-0.3 to 0.3	-0.8 to -0.8	-35	-29	1.9-3
	30	11	15	-0.1 to 0.1	-0.3 to 0.3	-39	-34	1.9-3
Feeding (Adult) feeding	10	42	57	-0.1 to 0.9	-1 to 1	-22	-18	1.3-3
	20	27	33	-0.8 to 0.8	-1 to -1	-27	-24	1.3-3
	30	17	25	-0.5 to 0.5	-0.9 to 0.9	-37	-33	1.3-3
Feeding (Larvae)	10	43	54	-0.9 to 0.9	-1 to 1	-27	-21	1.7-2.7
	20	24	32	-0.6 to 0.6	-1 to 1	-30	-27	1.7-2.7
	30	15	22	-0.4 to 0.4	-1 to 0.9	-38	-34	1.7-2.7
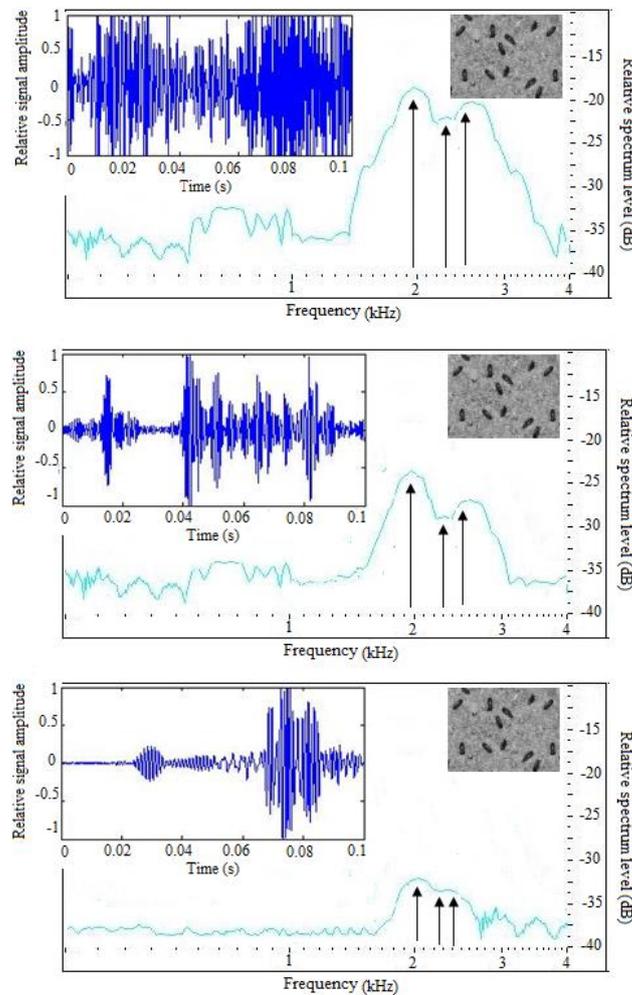
Figure 6. The acoustic frequency of *Triboium confusum* inside a wheat grain mass having several larvae and adult insects (from top to bottom: distance of 10, 20 and 30 cm, respectively).

sensing the audio frequency of both the adult and larval stages of the flour beetle and hence detecting the pests.

CONCLUSIONS

Supply of healthy and quality food is one of the factors considered by governments. Since flour beetle is one of the most common pests in stored products, early diagnosis is essential to carry out preventive measures. With the help of modern electronics and facilities an integrated circuit along with a sensitive audio sensor were developed in order to identify the sound of the insects with very low sound level intensity. By designing three sets of tests the performance of the circuit in recording and detecting of the insect (larvae and adult) was evaluated and the following results were concluded:

The sound system capable of detecting flour weevil within a mass of wheat grain, either in larval stage or adult from a distance of 30 cm.

The frequency produced by larvae is mainly due to its feeding and had peak intensity at the frequency of about 2.4 kHz. For adult insect, two peaks of intensity were observed at frequency of about 2 kHz (feeding frequency) and 2.3 kHz (walking frequency).

The duration of an audio signal for both larvae and adult insect decreases with increase in distance between insect and sensor.

The signal intensity level for both larvae and adult insect decreases with increase in distance between insect and sensor.

The audio frequency characteristics recorded from infected grain mass with several larvae and adults were very close to those obtained from individual larvae and adult tests and hence demonstrate that the proposed sound system can be used for insect detection in stored grain bulk.

The adult insect feeding frequency has higher intensity level than its walking frequency and also feeding frequency of larvae. The lowest intensity level observed for adult walking frequency at different distances.

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امکان سنجی تشخیص صوتی مراحل مختلف شپشه آرد (*Triboium confusum*) در توده دانه با استفاده از یک سنسور صوتی

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چکیده

پیشرفت های اخیر در تکنولوژی کامپیوتر و همچنین پردازش سیگنال و به رسمیت شناختن الگو، امکان شناسایی خودکار گونه آفات را بر اساس تشخیص سیگنال‌های صوتی آنها فراهم کرده است. یکی از مشکلات دریافت سیگنال‌های صوتی حشرات ریز پایین بودن سطح شدت صدای آنها می‌باشد. با طراحی یک حسگر صوتی تقویت شده پیزوالکتریک و مدار تشخیص بر اساس پایگاه داده، امکان دریافت سیگنال‌های صوتی با شدت پایین‌تر از حد شنوایی انسان (زیر صفر دسیبل) امکان پذیر شد. آفت مورد استفاده در این آزمایش شپشه آرد بود که سیگنال‌های دریافتی از آن برای سه حالت لارو، حشره بالغ و ترکیبی از هر دو در دانه گندم در سه فاصله ۱۰، ۲۰ و ۳۰ سانتیمتری از حسگر صوتی مورد بررسی قرار گرفت. خصوصیات فرکانس‌های دریافتی شامل رنج، زمان، دامنه و سطح شدت فرکانس برای هر سه حالت در فاصله‌های تعیین شده استخراج شد. صدای تولید شده توسط لارو دارای اوج شدت فرکانس در محدوده) kH 2.4 فرکانس تغذیه) و صدای حشره بالغ دارای دو اوج شدت صدا در محدوده فرکانسی) kH 2 فرکانس تغذیه) و) kH 2.3 فرکانس راه رفتن) بود. این خصوصیات

متفاوت امکان تشخیص مرحله زندگی آفت، فاصله آفت تا حسگر و مکان تقریبی آفت را فراهم می‌کند. حسگر و مدار صوتی طراحی شده امکان تشخیص لارو، حشره کامل و یا هر دو آنها را با هم تا فاصله 30سانتیمتری دارد. با پیشرفت در برنامه نویسی این سیستم صوتی و مدارات مربوط به ان امکان تشخیص دقیق و به موقع یک آفت فراهم می‌گردد.