Optoacoustic intelligent sensor for real-time detection of fruit flies in McPhail traps

Fabiano Sandrini Moraes[1], Dori Edson Nava[2], and Vagner Santos da Rosa[3]

***Abstract*— This work presents the development of an optoacoustic sensor for use in intelligent traps with real-time detection of fruit flies *Ceratitis capitata* and *Anastrepha fraterculus* to be used in a McPhail kind trap. The sensor uses an array of infrared LED light source and photodiodes to make a light courtain. Fluctuation caused by the beating of insect wings and are detected by the sensor. The flying pattern of the flies ensures the flies will pass through sensor once. The captured signal is conditioned by the sensor hardware and is used to characterize the insect species for future classification and counting. The sensor is designed to be used in McPhail type traps and it is not a trap by itself. The sensor performance was evaluated through simulated experiments in the laboratory, where it proved to be promising for use with the insects of interest.**

I. INTRODUCTION

Fruit flies are an important pests that affect the fruit crops worldwide. They cause direct and indirect damages in production. The species of fruit flies of economic importance in Brazil belongs to three genera: *Anastrepha*, *Bactrocera* and *Ceratitis*. Among the species of fruit flies present in Brazil, those that present quarantine restrictions for importing countries are: *Anastrepha fraterculus* (Wiedemann, 1830), *Anastrepha obliqua* (Macquart, 1835), *Anastrepha grandis* (Macquart, 1846), *Ceratitis capitata* (Wiedemann, 1824) and *Bactrocera carambolae* Drew and Hancock, 1994 [1].

Data from the Brazilian Ministry of Agriculture show that fruit flies cause annual losses of up to US$ 120 million to Brazilian producers between production losses and control costs. The presence of flies also makes it impossible to export fresh fruit to more demanding and profitable markets such as Japan, the United States and Chile [2].

Fruit flies have wide geographic distribution and a large number of hosts. In the southern region of Brazil, *A. fraterculus*, figure 1, develops in several fruit trees, which can make production unfeasible if control measures are not adopted [3].

The control of fruit flies is usually done in an unregulated way by fruit growers using insecticides in the form of toxic baits or by coverage without knowledge of the infecting species, the levels of infestation and the distribution of the hosts. This type of crop management has several undesirable consequences such as environmental impact, declining fruit quality, export restrictions due to the presence of chemical residues and an increase in the cost of production [3].

Fig. 1. *A. fraterculus*

Among the alternatives to assist in the management of fruit flies, currently efforts are being directed towards the technologies used in Precision Agriculture. These technologies include a set of tools that combine sensors, information systems, adapted machines and knowledge management to improve production and minimize variability and uncertainty in agricultural systems that provide means to guarantee food quality [4].

For the management of fruit fly, among the techniques proposed by precision agriculture, it is fundamental to realize the monitoring through the use of traps filled with an attractive bait. One of the possible types of traps is McPhail, figure 2, which uses food attractions to catch adults of fruit flies. It is also possible to use sex pheromones to attract adults and in this case has the example of paraferomon used in Deltas traps to attract *C. capitata*. When traps are used for monitoring, it is necessary for a technician to perform the inspection of the traps by classifying and counting the captured flies [3].

This work presents the development of an optoacoustic sensor to be used in the design of an intelligent monitoring trap to be used in a McPhail type trap. The goal is not not only to count the flies but also to identify it because only some species are pest. The McPhail trap was chosen because the flies need to fly vertically upwards to get the way into the trap. This system will reduce the need for technician intervention in monitoring, contributing to minimize human error in the identification and counting of flies and a reduction in the cost of the monitoring program.

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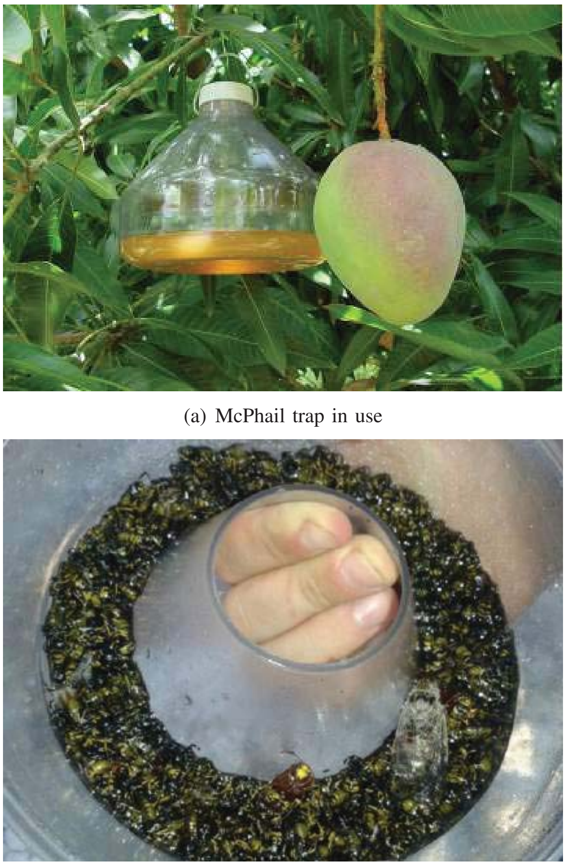


(a) McPhail trap in use

(b) McPhail trap base with captured flies

Fig. 2. McPhail trap

As the flies are permanently trapped inside the McPhail trap, conventional monitoring system can be used as backup in an actual application. This technology can be integrated into an information system to support farmers to choose an effective pest control technique at the right time, reducing costs.

The use of optoacoustics for insect identification was presented by [5], where photo-receptors were used to capture the variation of the ambient light generated by the beating of the insect wings during flight. This variation of light is processed and determines the frequency of the beating of the insect wings.

According to [6], this frequency depends on the physiological characteristics of the species and can be used for its identification.

Currently, this technique has been employed in the development of an intelligent mosquito trap [7], [8].

Optoacoustic sensors were also used in the design of the intelligent trap for the fruit fly of the olive tree *Bactrocera oleae* [9], [10].

The goal of this work was to develop an optoacoustic sensor for intelligent traps aiming the identification and counting of the fruit flies collected in real time.

II. MATERIALS AND METHODS

There are several technologies for identification and automatic detection of insects, but the two main ones are the acoustic sensors and the systems of computer vision [11].

In acoustic technology, recent studies are being carried out using accelerometer sensors, piezoelectric sensors, microphones and ultrasonic transducers. The use of accelerometer and piezoelectric sensors is associated with the detection of insects by vibrations in the soil, in bulk grains or plant tissues. Ultrasonic sensors are indicated for detection in wood. Microphones are best suited for picking up ambient sounds such as insects during flight, being a method that shows great sensitivity to ambient noise [11].

The use of optoacoustic sensors was used as an option to use microphones in [5]. These sensors measure small fluctuations of light caused by the beating of the wings while flying through the sensor, as the projected shadow varies with the wings movement, instead of a sound wave in the case of microphones. Both will produce a characteristic noise that can lead to the identification of the insect type by means of its spectral signature.

According to [9], there are clear advantages in the use of optoelectronics instead of microphones:

- It picks up the signal only when the transmitter path to the receiver is interrupted while a microphone picks up sound from all directions;
- It have a very high signal-to-noise ratio (they are practically silent) while microphones record all sound sources (eg birds, cicadas, wind) and therefore recordings can become very noisy;
- Microphones, while they can be protected in various ways against weather conditions, are more vulnerable to open field conditions

A. Proposed Optoacoustic Sensor

The proposed sensor was based on the work presented in [9], [10], where in these articles are shown the steps of the development of an intelligent trap for fruit flies of the olive tree *Bactrocera oleae*.

For the design of the sensor a 3D model was created. For the dimensions of the passage opening of the flies, 6.5cm for the width (l) and 6.5cm for the length (c) were stipulated, as shown in figure 3. These dimensions were based on the dimensions of the passage hole of a McPhail trap, enabling the coupling of the sensor to the trap.

In the definition of height (h), the acquisition time of 100ms suggested by [10] and the flight speed of $0.25m/s$ obtained in [12] were taken into account. Thus, the minimum height is given by

$$h = \frac{0.25m}{s} 0.1s = 2.5cm \quad (1)$$

Based on the minimum height $h = 2.5cm$ obtained in equation 1, $3.0cm$ was used for the height taking into account a tolerance for variation of flight parameters due to climatic conditions as [13]. The indicated parameter is shown in figure 3.

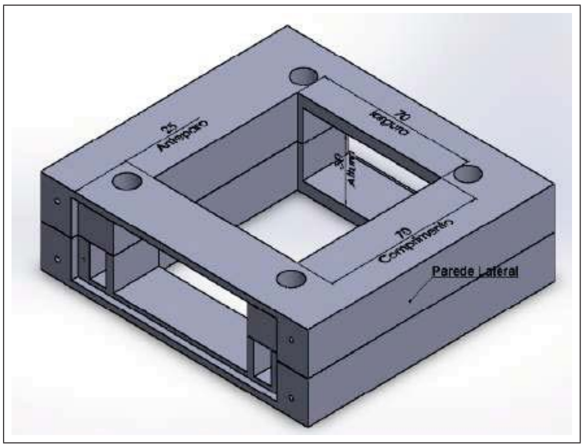


Fig. 3. Base Design of Optoacoustic Sensor - Passing Area

To reduce the possibility of noise generated by interference from external lights to the sensor, a $2.0cm$ shield was inserted and the side walls were placed, as shown in figure 3. In this way, both the transmitter and the receiver are isolated from ambient light.

In the construction of the optoacoustic sensor base, a Da Vinci 1.0 xyz 3D printer with a PLA filament was used. The printer has been configured for a 50% fill-in-the-hive, thick bark, $0.1mm$ layer height, and slow speed.

In relation to the emitter circuit of the sensor were used LED-IR TIL32, which has as main characteristics, wavelength of 940nm, angle of light dispersion with 35°, direct current of 20mA and direct voltage of 1.3V.

Thus, taking into account the angle of light dispersion of the TIL32 (35°), the size of the shield (25mm), the height of the passage zone (30mm), the series connection of the IR-LEDs and the lower voltage power supply was stipulated with 8V.

The number of rows in the emitter circuit array was determined by

$$N°Rows = \frac{30mm}{\tan 17.5° * 25mm} = 3.8 \quad (2)$$

to ensure the presence of light throughout the passage zone the number of rows was rounded to 4.

The number of columns of the sender matrix was determined by

$$N°Col = \frac{8V}{1.3V} = 6.15 \quad (3)$$

to ensure that the voltage required to operate the IR-LEDs does not exceed 8V, the number of columns has been rounded to 6.

Thus the sensor emitter circuit was implemented with 4 rows and 6 columns. The schematic diagram of the implemented circuit is shown in figure 4.

TIL78 phototransistors connected in parallel in photovoltaic mode were used for the sensor receiver circuit. The TIL78 has a wavelength of 940nm, current generated under light of 1mA, dark current of 20nA and reception angle of 40°.

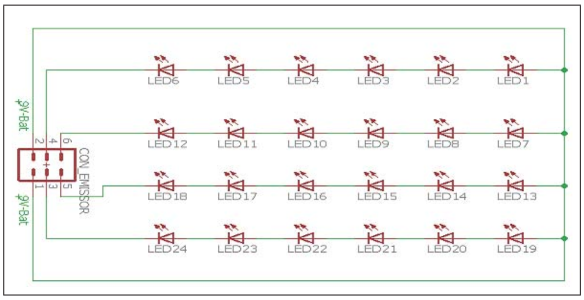


Fig. 4. Optoacoustic sensor emitter circuit

Thus, the emitter circuit of the sensor was defined taking into account the width of the passage (70mm), the size of the shield (25mm) and the angle of light reception (40°).

The number of columns in the matrix of the sensor receiving circuit is defined by

$$N°Col = \frac{70mm}{\tan 20° * 25mm} = 7.69 \quad (4)$$

to ensure that there are no shadow areas in the passing zone the number of columns has been rounded to 8.

The number of rows in the receiver circuit has been set to be symmetrical to that of the transmitter circuit, thus being defined as 4.

Thus the sensor receiver circuit was implemented with 4 rows and 8 columns. The schematic diagram of the implemented circuit is shown in figure 5.

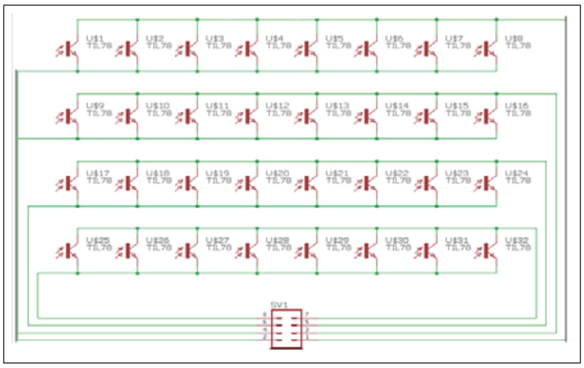
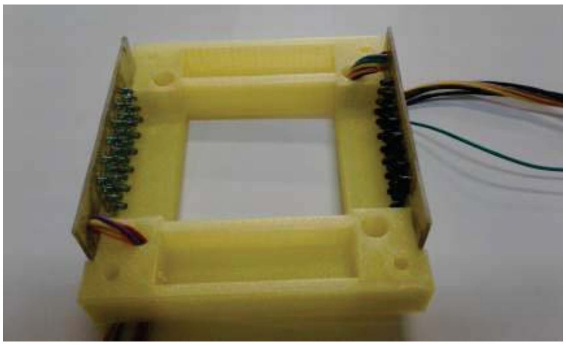


Fig. 5. Optoacoustic sensor receiver circuit

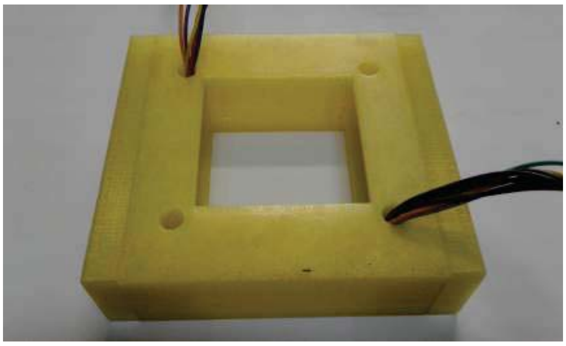
Figure 6(a) shows the details of the emitter (left) and receiver circuit (right) assemblies and figure 6(b) shows the completed sensor.

B. *Optoacoustic sensor hardware*

The block diagram of the proposed hardware for treatment of the signal generated by the implemented optoacoustic sensor is shown in figure 7.Where the signal current generated by the light incident on the photodiodes of the receiver is initially converted into voltage by the transimpedance amplifier. The signal is then passed through a high pass filter. This filter has the function to eliminate the signal of offset caused by the illumination, leaving only the signal generated by the variation of the light caused by the movement of wings of the insects. After the low pass filter limits the



(a) Detail of the emitter circuit(left) and receiver circuit(right) assemblies



(b) Finished optoacoustic sensor

Fig. 6. Optoacoustic sensor

upper frequency of the signal functioning as an antialiasing filter. Finally the filtered signal is amplified to the full scale of the A/D converter of the microcontroller block. The microcontroller block is designed to carry out the digital-to-digital converter of the signal generated in the sensor, perform signal processing by identifying and counting the insects, transmit the data obtained and control the emitter circuit through the LED-IR drive block.R. The LED-IR block has the function of controlling the luminous intensity of each row of the emitter circuit matrix and switching on or off each row independently under the command of the microcontroller block.

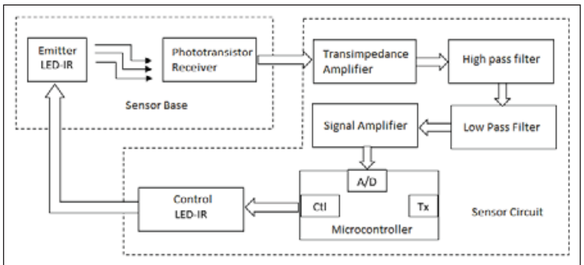


Fig. 7. Optoacoustic sensor hardware block diagram

The transimpedance amplifier, high pass, low pass amplifier blocks and signal amplifier were implemented using TL082 operational amplifiers with single supply 5V. The gain of the transimpedance amplifier was set to 1000. The high pass and low pass filters were specified using the approximation Butterworth, implemented with the second-order MFB topology, with cut-off frequencies of 60Hz for high pass and 1000Hz for low pass. The signal amplifier was implemented in the non-inverting configuration with adjustable gain from 1 to 101.

The LED-IR drive block consists of four adjustable current sources from 6.62mA up to 125mA. Each of them triggers a row of the emitter circuit of the sensor being switched on or off through the microcontroller block.

C. Experiments

The experiments were carried out with the objective of verifying the operation of the sensor and its possibility of use with insects. For this, the system noise, the best configuration of the emitter and receiver circuit matrices, and the sensor response to different stimulus frequencies was evaluated.

Prior to field test, an insect wing beat simulator was used. The simulator was developed using a DC motor of 12V/6000rpm and a wire with a diameter of 0.5mm fixed to its axis. When the simulator is activated the motor rotates the wire at a constant speed, which when inside the sensor passage area causes fluctuations in the light received by the phototransistors at a constant frequency determined by the motor supply. The simulator coupled to the optoacoustic sensor to perform the experiments is shown in figure 8. At the output of the signal amplifier circuit was connected a Tectronix TBS1062 oscilloscope with bandwidth of 80MHz and sampling rate of 1GS/s. The signal measured with the oscilloscope was used to verify the rotation frequency of the simulator and compare with the signal captured by the sensor.

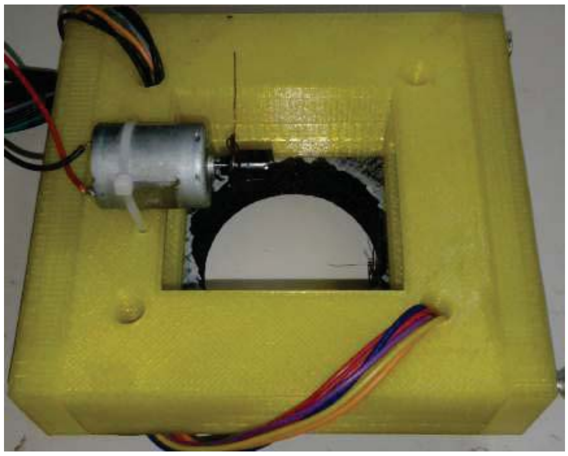


Fig. 8. Simulator coupled to the sensor to perform the experiments

Signal acquisition was performed using an Asus K84C Series notebook with 2.20GHz Intel (R) Core (TM) i3-2330M processor, 4.00GB RAM, Windows 7 Home Basic operating system, and Realtek High Definition Audio version 6.14.0.3097. Thus, the sensor output was connected to the microphone input of the notebook and used Audacity software version 2.1.3 for recording audio files. The recording was performed for a time of 60s, in WAV format files, with a sample rate of 44100Hz, mono and with resolution of 32bit float.

The analysis of the captured audio was performed using SciLab software version 6.0.0. Where the recorded WAV file is read and carried through the time domain to the frequency domain using the FFT function. After the graph of distributed energy in the frequency spectrum is generated for analysis.

The experiments were conducted with current sources that power the LED-IR-regulated at 20 mA, using a PS23023 power supply set to 9V, in a laboratory with illumination produced by tubular fluorescent lamps with a color temperature of 6500K and a luminous intensity 7010lux on the sensor.

III. Results

Initially, the sensor performance was evaluated in relation to several sources of noise, being verified the noise generated by the ambient illumination, the noise generated by the emitter circuit, the noise generated by the receiver circuit/sensor hardware and the noise caused by the mechanical vibration of the simulator when attached to the sensor.

Thus, it was verified that the main source of noise is the electric network with fundamental frequency of 60Hz and its harmonics, as shown in the graph generated by the experiment for noise evaluation, figure 9.

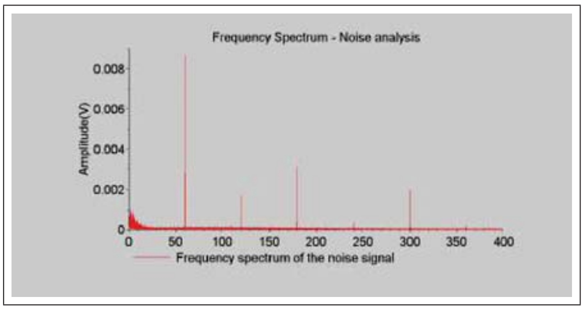


Fig. 9. Noise evaluation experiment graph

Regarding the influences of the components of the sensor, it was verified that external lighting is responsible for 5% of the total noise, the emitting circuit for 50% of total noise and the rest is caused in the receiver circuit and sensor hardware. It was observed that the mechanical vibration caused by the insect wing simulator did not generate considerable noise.

For the evaluation of the best configuration of the lines of the emitter and receiver circuit matrices, an experiment was performed with the two circuits with four rows, the receiver with one row and the emitter with four rows and the receiver with four rows and the emitter with a row. The signal-to-noise ratio of the fundamental frequency signal intensity with the 12V / 6000rpm simulator and the intensity of the generated noise signals were used as the evaluation metric. The results obtained were:

- Four rows on the receiver and four rows on the transmitter: SNR(60HZ)=6.66 e SNR(45Hz)=0.375;
- One row on the receiver and four rows on the transmitter: SNR(60HZ)=2.21 e SNR(45Hz)=0.19;
- Four rows on the receiver and onde row on the transmitter: SNR(60HZ)=43.33 e SNR(45Hz)=5.41.

Thus, the best configuration found was with the emitter with one row and the receiver with four lines. The graph generated with the experiment performed with this configuration is shown in figure 10, where it is noticed the appearance of a noise with frequency of 45Hz due to the overlap of signal caused by multiple light sources.

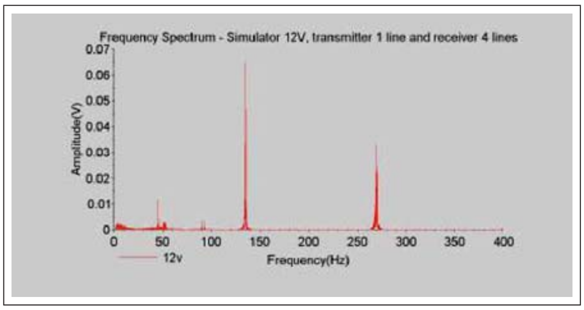


Fig. 10. Graph of the evaluation experiment of the emitter and receiver matrices

For the analysis of the performance of the sensor before the stimuli of different frequencies were carried out experiments with the simulator with 4V, 8V, 12V and 16V. The results of the experiments are shown in figure 11.Note that the sensor showed a fundamental frequency response of 177.23Hz with 16V, 134.96Hz with 12V, 93.48Hz with 8V and 46.48Hz with 4V which is as expected. Regarding its harmonics, the intensity decay is observed with the increase of the harmonic order as expected, with the exception of the 46.48Hz signal that its intensity is affected by the high pass filter that has a cut-off frequency at 60Hz

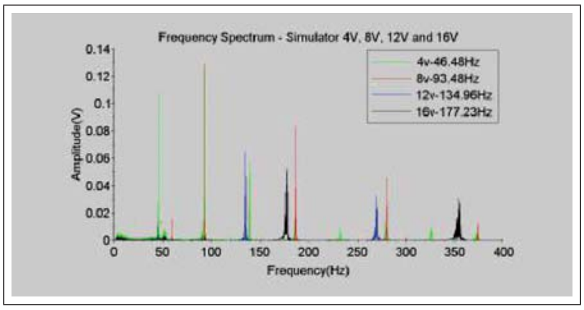


Fig. 11. Graph of the performance evaluation experiment in different stimuli

The accuracy of the developed optoacoustic sensor was verified by comparing the fundamental frequency of the signal captured with the oscilloscope to the fundamental frequency response obtained in the processing of the signal captured in the computer.This was obtained in the oscilloscope and in the computer, respectively, 177.9Hz and 177.23Hz with 16V, 134.6Hz and 134.96Hz with 12V, 89.9Hz and 93.48Hz with 8V and 44.3Hz and 46.48Hz with 4V. The signal captured on the oscilloscope with the simulator at 12V is shown in figure 12, where the harmonic distortion and the fundamental frequency value of 134.6Hz are verified.

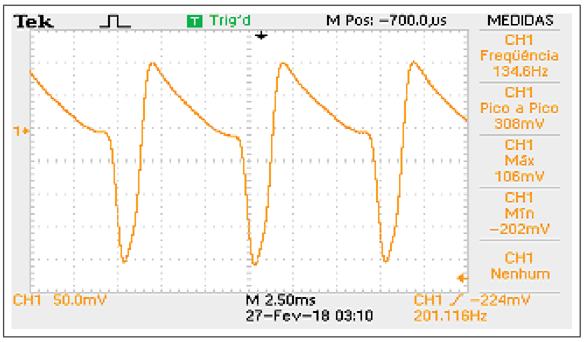


Fig. 12. Signal captured on oscilloscope with simulator at 12V

Thus, taking into account that as [10] and [6] the fundamental frequency of the sound caused by the fly's wings beat *C. capitata* is approximately 200Hz and *A. fraterculus* fly is approximately 90Hz which may be simulated approximately the simulator with 8V and 16V. The sensor showed promise for experiments with insects, identifying correctly to the fifth harmonic of the signal.

IV. Conclusion

In this work the development of an optoacoustic sensor for use in intelligent traps for fruit flies C. capitata and A. fraterculus was presented. A sensor base was developed using a 3Dxyz printer with its dimensions designed for use in a McPhail trap with the insects of interest. The emitter and receiver circuits were designed using TIL78 LED-IR and TIL32 phototransistors mounted in the form of matrices with a row and column ratio to provide a uniform light barrier and no shadow areas in the sensor passage zone, leading to taking into account the characteristics of the TIL78 and TIL32 and the minimum supply voltage of the sensor.

For the sensor hardware, a circuit for the treatment of the signal generated in the sensor, consisting of a transimpedance amplifier, a high pass filter, low pass filter, signal amplifier and IR-control circuit was implemented.

Based on the experiments carried out, the sensor implemented and its hardware presented satisfactory and promising results for use with the insects of interest. Since the source of noise found was generated by the electric network at 60 Hz, the best configuration of the receiver and emitter matrices was with one row in the emitter and four rows in the receiver and the sensor presented the expected results with stimuli of different frequencies.

A. Future works

For future work we intend to:

- Perform signal capture in the laboratory using flies bred in captivity and captured in the wild;
- Study of other techniques for obtaining the frequency spectrum of a signal such as Fourier series and Wavelet transform;
- Study on voice recognition techniques to be applied to the recognition of insects;
- Development of an intelligent trap using real-time optoacoustic detection of insects.

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