

ANALYSIS OF SIGNAL OF X4 UNMANNED AERIAL VEHICLE

Marzena Mięsikowska

*Kielce University of Technology
Faculty of Mechatronics and Mechanical Engineering
Department of Applied Computer Science and Armament Engineering
Tysiąclecia Państwa Polskiego Avenue 7, 25-314 Kielce, Poland
tel.: +48 413424334, fax: +48 413448698
e-mail: marzena@tu.kielce.pl*

Mirosław Nowakowski, Wojciech Lorenc, Marcin Chodnicki

*Air Force Institute of Technology
Ksiecicia Bolesława Street 6, 01-494 Warszawa, Poland
tel.: +48 261851300, fax: +48 261851300
e-mail: mirosław.nowakowski@itwl.pl, wojciech.lorenc@itwl.pl, chodnm@itwl.pl*

Abstract

Unmanned aerial vehicles are increasingly used in military service and in everyday life. Drones can be used for many purposes i.e. recreation, military applications or to increase the safety of citizens. Unmanned aerial vehicle can become a source of information, based on which object/operator can make a certain decisions. Unmanned aerial vehicles are increasingly used in ecological research. UAV can be capable of making sophisticated maps and may scan terrain for forest fires. They can contribute to safe infrastructure maintenance and management. Often, however, these objects being in the possession of civilians can become a source of danger and impact on privacy. It is therefore necessary to detect and recognize such objects in a real time. The aim of this study was to analyse the acoustic signal of unmanned aerial vehicle equipped with four rotating propellers – X4 structure (12000 rpm/min). The maximum speed of the object is 60 km/h and the ceiling to which it can operate flights reaches 1500 m AGL. The acoustic signal was acquired by Olympus LS11 digital recorder. Recordings were performed when the object is away from the recording equipment at the distance of 1 km. Analysis of the recorded signal can provide a significant information about the unmanned aerial vehicle. Results showed that some specific characteristic signal features are clearly visible in the signal even if the object is far away from the recording equipment.

Keywords: *unmanned aerial vehicles, drones, time-dependent frequency analysis, signal analysis*

1. Introduction

Unmanned aerial vehicles (UAV) are increasingly used in military service and in everyday life. Drones can be used for many purposes i.e. recreation, military applications or to increase the safety of citizens. UAV are being increasingly used in ecological research to approach sensitive wildlife in inaccessible areas [1]. Inexpensive drones can be capable of making sophisticated maps [2]. UAV may scan terrain for forest fires and deliver courier packages. Drones can be also used as a tool for exploring potential benefits to safety managers within the jobsite. They can contribute to safe infrastructure maintenance and management. Often, however, these objects being in the possession of civilians can become a source of danger [3]. Natural controls, organizational and industry self-regulation, co-regulation and formal laws are needed to regulate drone situation [4], especially its impact on privacy. In military purposes, drones are attractively seen as possibility to counter insurgents and terrorists [5]. UAV can be very useful because they can operate in area where human life can be endangered. Drones can be equipped in specialized devices/sensors and provide relevant information to the operator. Because the UAV can become a source of

information based on which object/operator can make a certain decisions, and they can appear in restricted areas and impact on privacy, it is therefore necessary to detect and recognize such objects in a real time.

The aim of this study was to perform analysis of acoustic signal of X4 UAV. The analysis was performed in order to characterize the X4 UAV acoustic signal, mainly to detect the X4 UAV from various distances.

2. Methods

Unmanned Aerial Vehicle – the X4 UAV

The X4 UAV was used in this experiment -standard Phantom3 drone equipped with 4 rotating propellers rotating with 960 rpm/v (max RPM is around 12000 rpm at 12.6v). The maximum speed of the object is 60 km/h. The ceiling to which it can operate flights reaches 1500 m AGL. The considered object is presented in Fig. 1.



Fig. 1. The considered UAV in experiment, Phantom 3

Recording equipment

The acoustic signal of X4 UAV was recorded using Olympus LS-11 digital recorder. The sound was acquired with 44.1 kHz sampling rate and 16-bit signal resolution (mono recording). During measurements, the recording equipment was on 1.5 m height above the ground (microphone position). After performing measurements when recording equipment was on 1.5 m height above the ground, the recording equipment was attached to the drone.

Measurements

The measurements were taken in the following options according to the position of the recording equipment:

- recording equipment on 1.5 m height above the ground, the X4 UAV on 50 m height above the ground and moving away from the recording equipment to the distance of 1 km,
- recording equipment on 1.5 m height above the ground, the X4 UAV on 100 m height above the ground and moving away from the recording equipment to the distance of 1 km,
- recording equipment attached to the X4 UAV, the X4 UAV on 50 m height above the ground,
- recording equipment attached to the X4 UAV, the X4 UAV on 100 m height above the ground.

Procedures

Analysis of signal of the X4 UAV was performed using time-dependent frequency analysis and spectrograms. It was computed the windowed discrete-time Fourier transform of a signal.

3. Results

In Fig. 2, a spectrogram of the X4 UAV on 50 m height above the ground and over the recording equipment is presented.

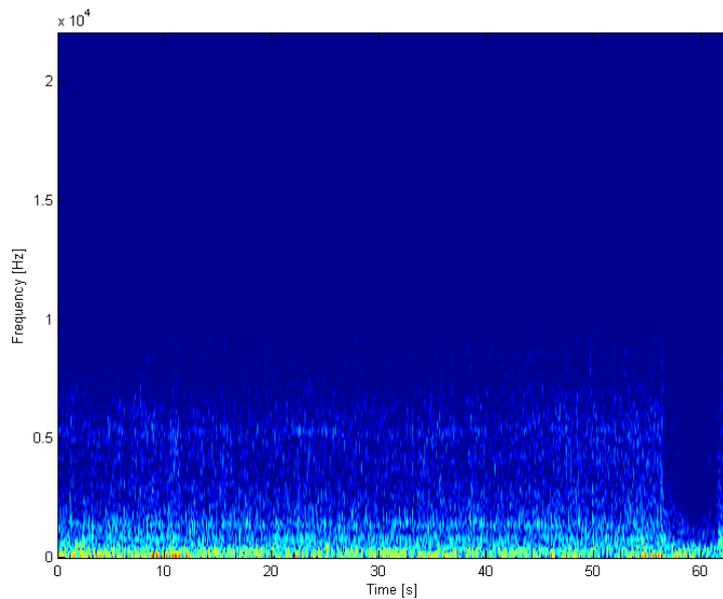


Fig. 2. The spectrogram of the X4 UAV on 50 m height above the ground and over the recording equipment

In Fig. 2, a characteristic band frequency value around 500 Hz for the X4 UAV is presented. Characteristic bands also appear around 1000 Hz, 2000 Hz, 5000 Hz.

Figure 3 presents a spectrogram of the X4 UAV on 100 m height above the ground and over the recording equipment.

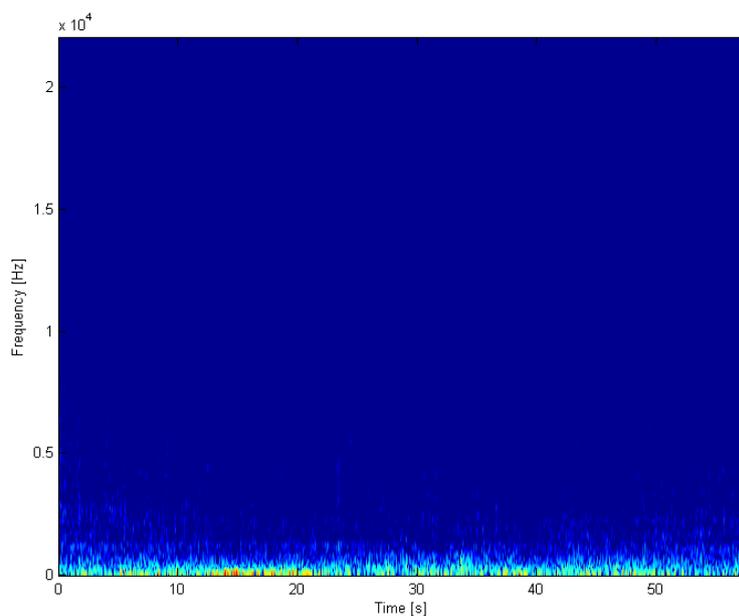


Fig. 3. The spectrogram of the X4 UAV on 100 m height above the ground and over the recording equipment

As presented in Fig. 3, a characteristic band frequency value around 500 Hz is also presented. Around 1000 Hz, 2000 Hz, and 3000 Hz the bands are less visible.

Figure 4 presents a spectrogram of the X4 UAV on 50 m height above the ground with the recording equipment attached to the drone.

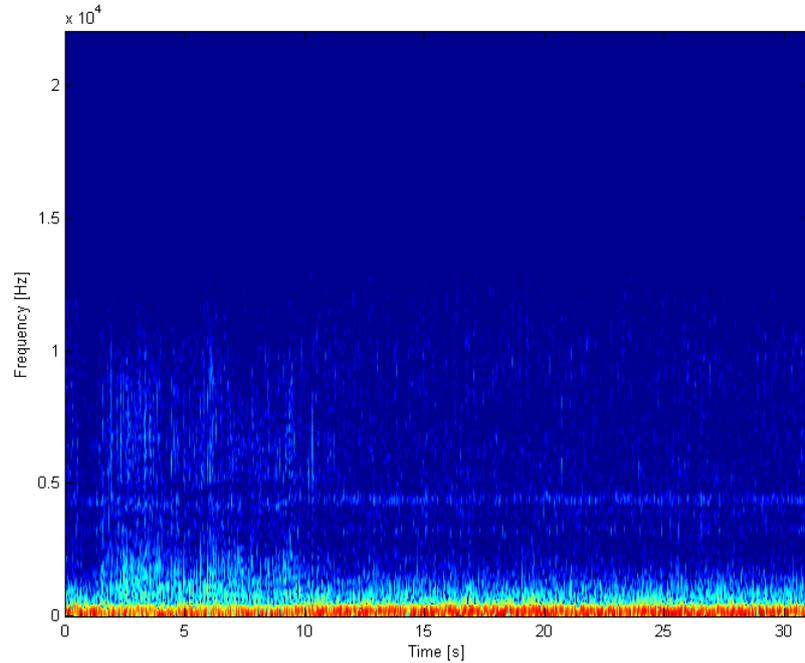


Fig. 4. The spectrogram of the X4 UAV on 50 m height above the ground with attached recording equipment

Figure 4 presents a characteristic band frequency value around 500 Hz. The band is much stronger than for the drone, which is being on the same height, and when the recording equipment is on 1.5 m height above the ground. Bands are also visible around 1000 Hz, 2000 Hz, and 4000 Hz.

Figure 5 presents a spectrogram of the X4 UAV on 100 m height above the ground with the recording equipment attached to the drone.

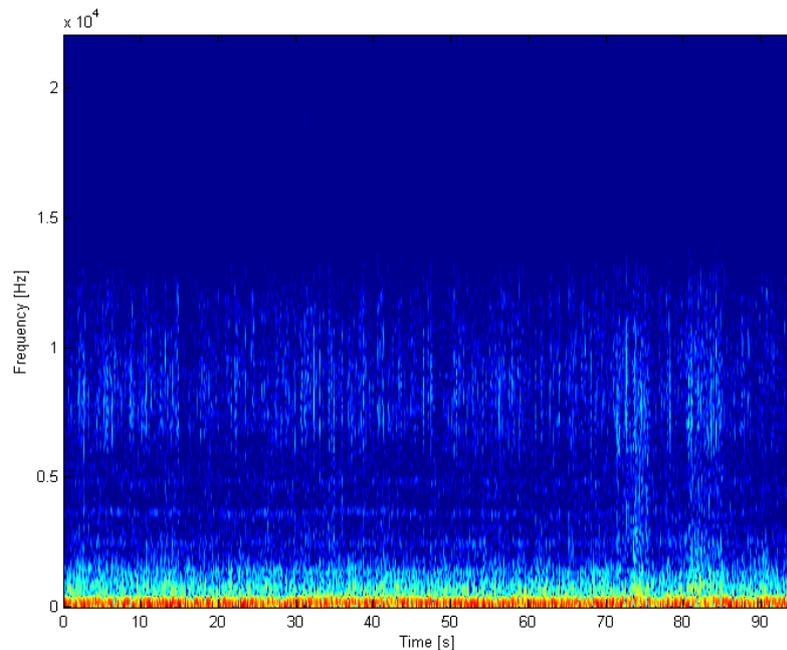


Fig. 5. The spectrogram of the X4 UAV on 100 m above the ground with attached recording equipment

Figure 5 presents a characteristic band frequency value around 500 Hz. The band is much stronger than for the drone being on the same height and over the recording equipment. Bands are visible around 1000 Hz, 2000 Hz, 3000 Hz, 4000 Hz, and 5000 Hz.

Figure 6 presents a spectrogram of the X4 UAV on 100 m height above the ground and away from the recording equipment at a distance of 1 km.

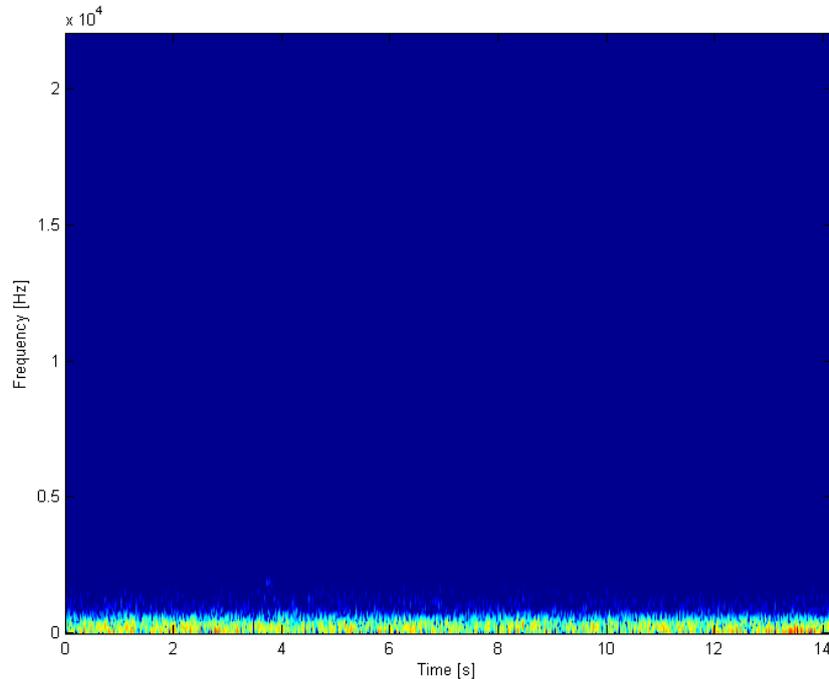


Fig. 6. The spectrogram of the X4 UAV on 100 m height above the ground at a distance of 1 km from recording equipment

As presented in Fig. 6, the characteristic frequency band appears around 500 Hz. The frequency band – 1000 Hz is also visible. Bands above 3000 Hz are not presented.

4. Conclusions

The aim of this study was to perform analysis of signal of the XU UAV. The analysis was performed using time-dependent frequency analysis and spectrograms in order to characterize the X4 UAV acoustic signal, mainly to detect the X4 UAV from various distances.

Spectrograms of the X4 UAV showed a characteristic band around 500 Hz on 50 m and 100 m height above the ground as well as on 100 m height above the ground and at a distance of 1 km. The characteristic band (around 500 Hz) is stronger presented on spectrograms for the X4 UAV with attached recording equipment. More frequency bands are visible for a drone with the attached recording equipment. When the recording equipment is on 1.5 m height above the ground and the drone is from the recording equipment at a distance of 1 km, less frequency bands can be observed. For such position of the drone, frequency band values did not exceed 3000 Hz.

Analysis of the recorded signal can provide a significant information about the unmanned aerial vehicle. Results showed that some specific characteristic signal features are clearly visible in the signal even if the object is far away from the recording equipment.

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