Helicopter detection and classification demonstrator

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ABSTRACT

A technology demonstrator that detects and classifies different helicopter types automatically, was developed at TNO-FEL. The demonstrator is based on a PC, which receives its acoustic input from an all-weather microphone. The demonstrator uses commercial off-the-shelf hardware to digitize the acoustic signal. The user-interface and the signal processing software are written in Matlab™. The demonstrator detects the noise from helicopters; the classification is performed using a database with helicopter-specific features. The demonstrator currently contains information of 11 different helicopter types, but can easily be expanded to include additional types of helicopters. The input signal is analyzed in real time, the result is a classification ranging from "no target" to "helicopter type x", e.g. Lynx Mk2. If the helicopter is classified, its relative speed is estimated as well. The algorithm was developed and tested using a database of different helicopters (hovering and moving) recorded at distances ranging from 90 meter up to 8 kilometer. The sensitivity to noise was investigated using jet, tank, artillery and environmental (wind and turbulence) noise as input.

Recently (May-June 1999) the demonstrator was tested during two field trials. Different types of helicopters were detected and classified, at various speeds, heights and distances. The detection range of the demonstrator is adjustable. However, when the range is set to approximately one kilometer, the demonstrator will obtain a high correct classification score, with very few false alarms.

The research is funded by the School of Military Intelligence of the Royal Netherlands Army. The objective is to develop a prototype of a helicopter detection and classification groundsensor, which can be used by the Royal Netherlands Armed forces for intelligence gathering of helicopter movements. Future research plans include the acoustic detection and classification of different types of fixed wing aircraft and UAV's.

Keywords: acoustic, detection, classification, helicopter

1. BACKGROUND AND INTRODUCTION

The last decennia the military use of helicopters has increased significantly. The acquisition and use of Apache, Chinook and Cougar helicopters by the Dutch armed forces are examples of this development. Although air defense systems are improved continuously, the detection of helicopters from the ground is difficult using traditional methods. Helicopters are able to use the terrain to avoid line-of-sight detection (human, radar and electro optic). The techniques to avoid detection are mainly used by helicopters that are tasked with reconnaissance, armor suppression and fire support missions.

During peace keeping missions the monitoring of helicopter movements of different parties is also a problem. The terrain often obstructs the line of sight of traditional detection equipment. Acoustic means can be used to improve the capability to detect low flying helicopters. The classification of the type of helicopter is also a possibility.

In a research contract for the Dutch Army a "helicopter classification technology demonstration system" was developed. The system consists of a microphone, amplifier and AD conversion electronics. Detection and classification is performed using a PC and Matlab™. The technology demonstrator is battery powered and placed in a portable weatherproof housing.

This paper contains a description of the demonstrator hardware, and a short description of the algorithms developed. Next, classification results on collected helicopter data (recorded at Dreux airfield, FR) are shown, as well as classification results calculated for different meteorological conditions. Finally, results are presented of the system's performance during recent field trails.

In *Unattended Ground Sensor Technologies and Applications II*, Edward M. Carapezza, Todd M. Hintz, Editors, Proceedings of SPIE Vol. 4040 (2000) • 0277-786X/00/$15.00

2. DESCRIPTION OF THE DEMONSTRATOR

The original contract included the development of a laboratory demonstrator, based on a desktop PC. Later the contract was extended to develop a military version of the demonstrator; to be deployed in the field along with the UGS system the Netherlands army is procuring.

2.1. Components of the Laboratory version

The laboratory version consists of a microphone, filtering and amplification electronics, and a processing unit. These components are shown in Figure 2.1.

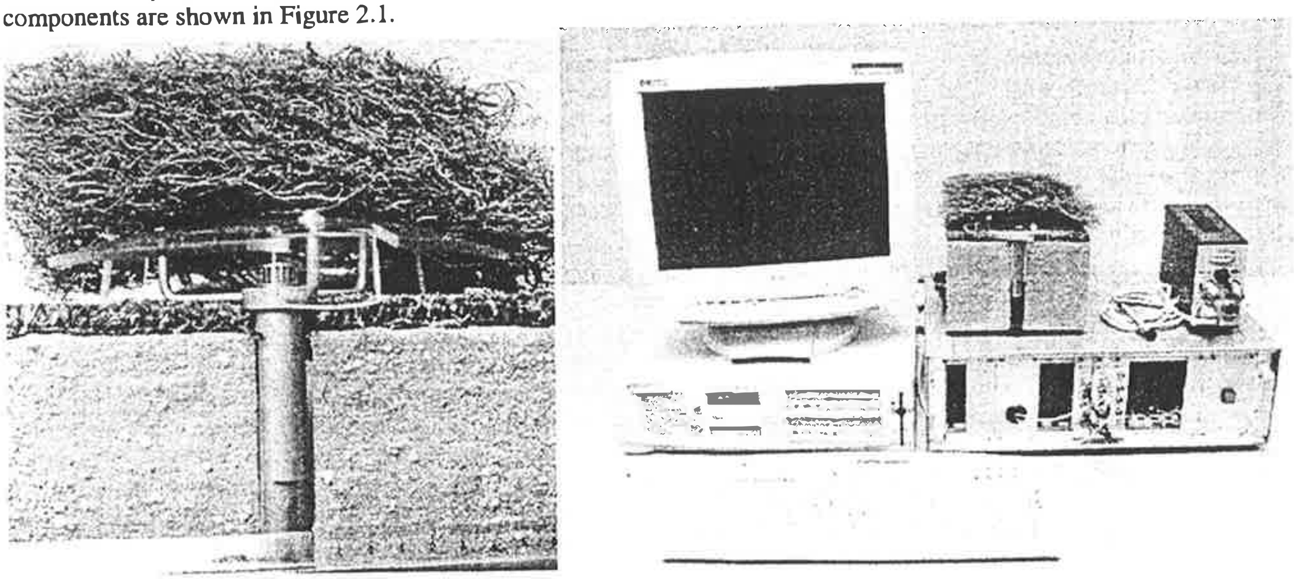


Figure 2.1: Left: Outdoor microphone with Perspex umbrella (scale in cm), Right: PC, 19 inch rack and microphones.

To condition the microphone signal for further processing, low pass filtering (anti-aliasing filter) and amplification is required. This is performed in a 19-inch rack, holding an 8th order Butterworth filter, amplifier and power supply. The rack has the possibility to include hardware for more microphones. The AD conversion is performed using a Data Translation DT322, (16 single channel analog input 16 bit resolution) data acquisition board. A HP Vectra VL II 400 MHz desktop PC is used to run the data acquisition and classification software. A Matlab™ user interface runs on the PC.

2.2. Components of the fieldable version

The hardware integrated for the fieldable demonstrator includes a laptop PC, National Instruments PCMCIA AD board, anti-aliasing filter, amplifier, outdoor weatherproof microphone and batteries. The electronics and laptop are placed in an aluminum case; the microphone and RS232 output can be connected to the outside of the case using Burndy connectors.
The anti-aliasing filter, amplifier and power supply are placed in a separate housing in the aluminum case. The fieldable version provides the classification results on the RS232 port. The demonstrator can be incorporated into the UGS system of the Dutch army (The demonstrator emits 3 bytes per second if a target is detected). A picture of the fieldable demonstrator is shown in figure 2.2.

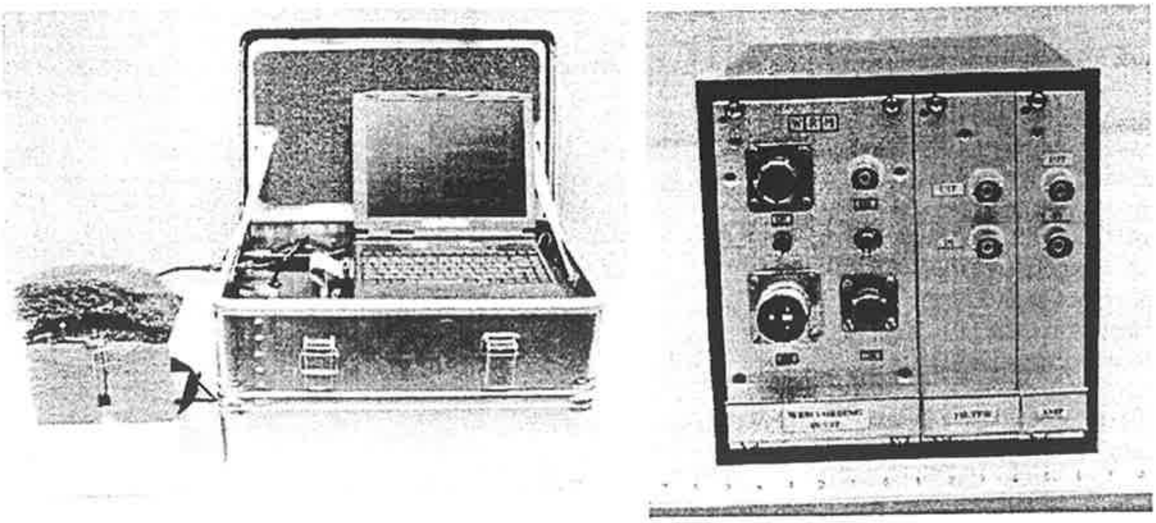


Figure 2.2: Left: Hardware integrated for the fieldable demonstrator includes a laptop PC, PCMCIA AD board, anti-aliasing filter, amplifier, microphone and batteries. The separate housing for three 19inch boards holding the power supply, filter and amplifier is shown on the right.

2.3. Algorithm and user interface description

The user interface and signal processing algorithms were developed to be able to perform research on helicopter detection, as well as real-time detection and classification of helicopters in the field. The input source can be chosen, either from a file or from an AD channel. At the moment, only one channel is used, with a samplerate of 1024 Hz. The user interface shows the input signal and the preprocessed spectrum. The output of the detection algorithm (classification code and helicopter type) is shown on the screen and is written to a log file for later analysis. The possibilities "no target", "alert", "main rotor" and "helicopter type x" are represented by classification code 1-4. The interface is shown in figure 2.3.

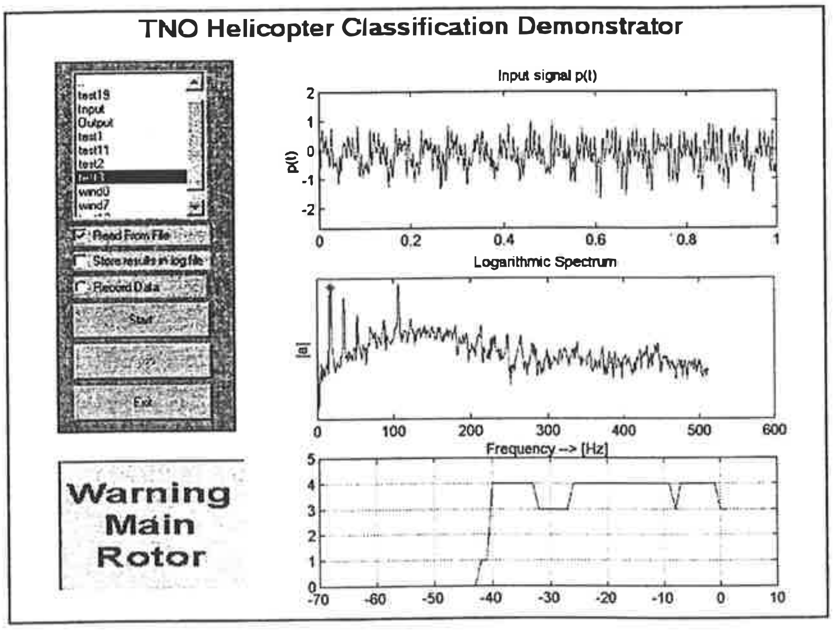


Figure 2.3: Demonstrator user interface with input selection menu, and three graphs showing the input signal, the spectrum and the classification code. The status is indicated in the lower left corner.

The demonstrator is built from modules that:

- perform algorithm initialization
- determine the set-up of the AD board
- handle the algorithm input
- perform preprocessing of the acoustic signal
- perform detection of "rotor like" signals
- perform the final classification of the signal.
- show and plot the results on the screen
- write the results to a file
- output the results to the RS232 port.

The execution time depends on a number of different tasks that are performed. The current version uses approximately 0.5 s, which includes all tasks, from reading data from the AD board to generating output. Further development to obtain a prototype is possible using the current demonstrator components. The algorithms written in Matlab™ can be easily adapted. Conversion to standard C for programming a DSP board is also possible.

During a demonstration, an interface can be used to display the demonstrator messages on another computer, acting as monitor. In the monitor window the sensor (demonstrator) position is shown on a map, together with the messages received from the demonstrator. The monitor window contains buttons to set up the connection with the demonstrator. If a helicopter is detected, the demonstrator position lights up in red. A button with the helicopter type to the right of the map lights up red as well. If only a main rotor is detected, a yellow button lights up. Next to the button the cumulative number of detections is shown. These counters can be reset using the "reset counters" button on the left of the window, see figure 2.4.

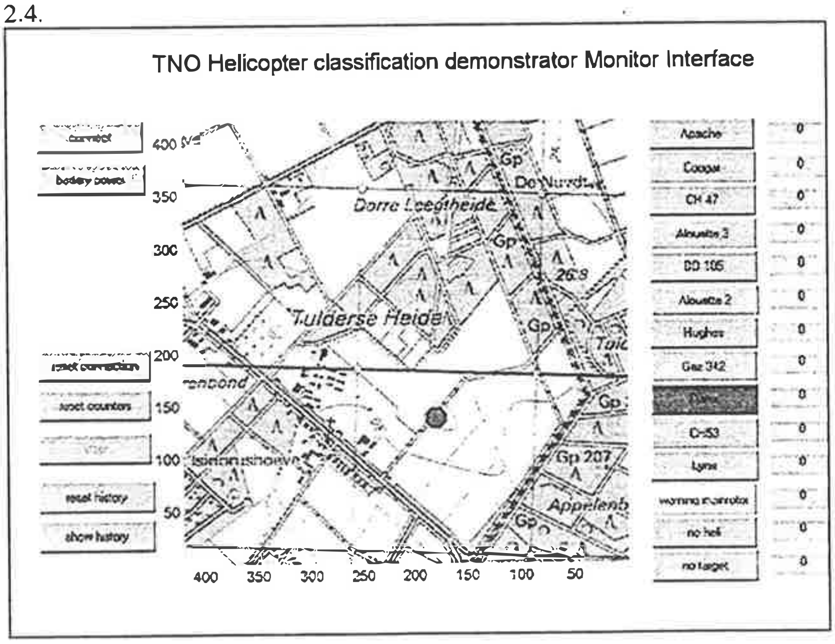


Figure 2.4: Helicopter classification monitor interface.

3. RESULTS ON DREUX DATA

For algorithm development and initial testing, a dataset recorded in 1988 at Dreux airfield in France was used. A detailed description of the dataset used is given in [1]. The data used in this example contains noise of helicopter type 3, recorded at 90 meters distance (first 64 seconds) with the helicopter hovering at approximately 5 m height. The other part of the data (192 seconds) shown in this example was recorded when the helicopter hovered at different positions on a circle with a radius of 2 km from the microphone position, at 5 m and 50 m height. The processed spectrum of the acoustic data is shown in the left part of figure 3.1 below.

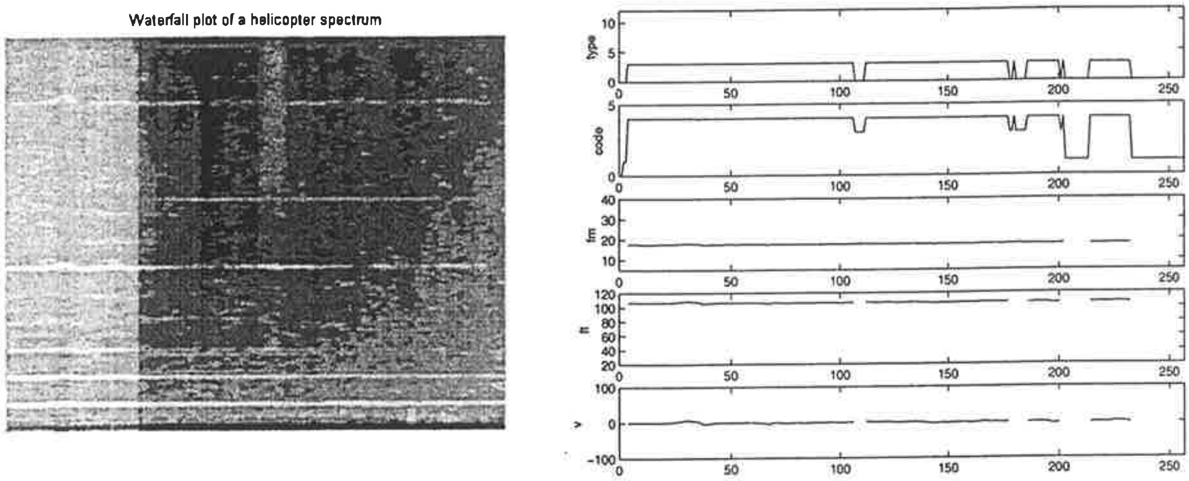


Figure 3.1: Left: Time frequency distribution of the data of helicopter type 3. Horizontal: time axis (0-256s). Vertical: frequency axis. Right: Classification results, from top to bottom: helicopter type, classification code, main rotor frequency, tail rotor frequency and helicopter speed. Horizontal: time axis (0-256s).

The resulting plot (figure 3.1 right part) contains the helicopter type, the classification code, the main rotor frequency, the tail rotor frequency and the speed. From the results we see that if the main and tail rotor frequency are visible in the spectrum, the algorithm can successfully determine the presence and the type of helicopter.

To show the algorithm can also detect and classify approaching helicopters, an example is given of the classification results on data of an approach of helicopter type 2. The helicopter is approaching from approximately 8 km distance, at a speed of approximately 60 m/s. The time frequency distribution of the data is shown in figure 3.2, left part.

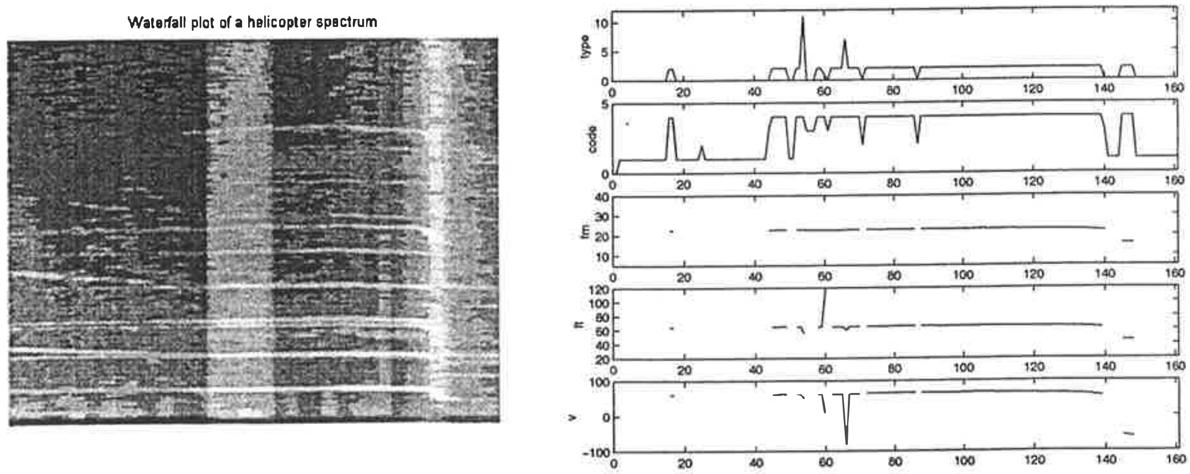


Figure 3.2: Left: Time frequency distribution of the approach data of helicopter type 2. Horizontal: time axis (0-160s). Vertical: frequency axis. Right: Classification results, from top to bottom: helicopter type, classification code, main rotor frequency, tail rotor frequency and helicopter speed.

From the classification results (figure 3.2 right) we see that the algorithm detects the helicopter at t ~ 15 s, approximately 120 s before it has reached CPA (which happens at t ~ 140). The detection is lost after the initial detection, and resumes at t ~ 45 s, approximately 90 s before the helicopter is overhead. One of the reasons (besides propagation conditions) is that the recordings were made in 1988, and required changing of the amplification to keep the signal within the dynamic range of the recorder. When the amplification is decreased (in this case), the detection is lost temporarily.

From the dataset recorded in Dreux, a subset was chosen for testing the algorithms. The subset consists of hover data recorded at 90 m and 2000 m distance, and approach data from approximately 8000m until CPA. The total results of the algorithm on the testset are given in figure 3.3.

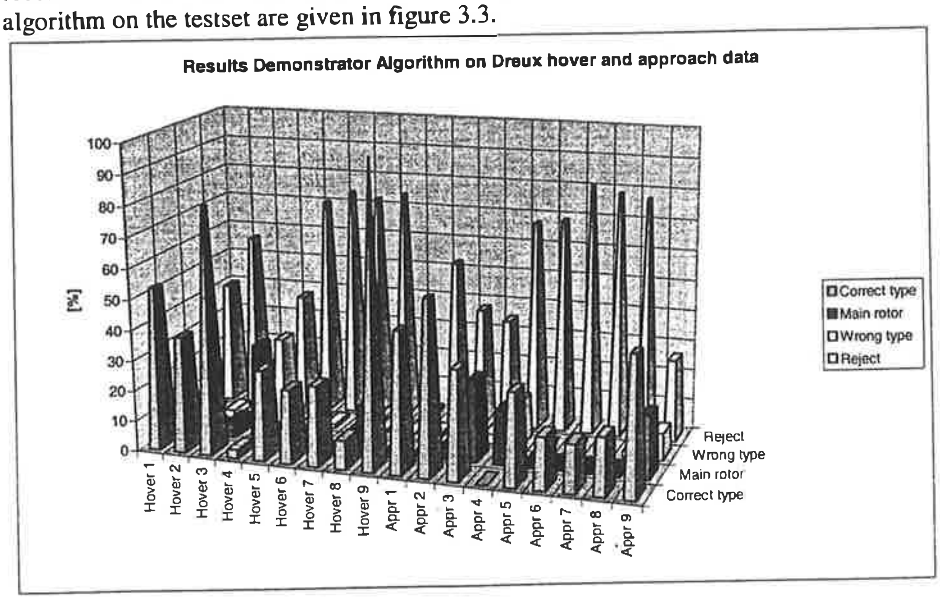
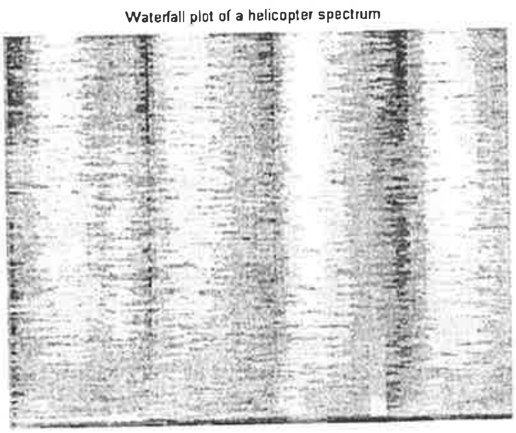


Figure 3.3: Results of the classification algorithm on the Dreux helicopter data. The graph contains percentages of correct classification, main rotor detection, false classification and rejection of the signal, for 9 helicopter types in hover and approach situations.

The graph shows that the algorithm can successfully detect and classify different types of helicopters. Wrong classifications occur occasionally, but mostly for helicopter type 4. The errors for type 4 occur because this helicopter has a tail rotor frequency outside the algorithm's current frequency range.

During the same measurement campaign jet noise was recorded. The current algorithm rejects those signals successfully. The log spectrum of 4 (different) jet passages is shown in figure 3.4.



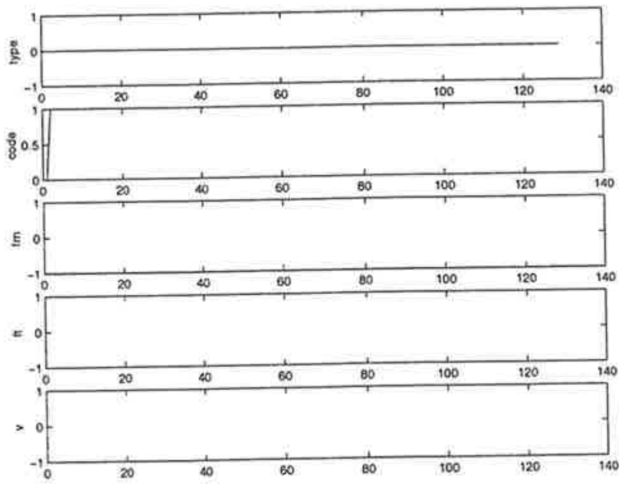


Figure 3.4: Left: The Time frequency distribution of four consecutive passes of a jet aircraft. The x axis of the plot is the time (total of 128 s), the y axis is the frequency. Left: Classification results of the jet spectra.

The classification result on the spectra is shown in the right part of figure 3.4. The graph shows the type detected (type 0 for no target), and the classification code (code 1 for rejection of the spectra). Obviously the main rotor and tail rotor frequency could not be determined.

4. CLASSIFICATION RESULTS ON WINDNOISE DATA

To determine the performance of the helicopter detection algorithms under different meteorological conditions, acoustic measurements of wind noise and the corresponding meteorological conditions were performed during a one-year period. The measurements were performed on a military airfield in the Netherlands. The procedure to estimate the performance of the classification algorithm for different wind speed conditions is reported in [2,3]. This procedure is repeated for the current version of the algorithm. Simulated noise of helicopter type 3 is used as an input signal. The signal is submitted to a propagation filter in the frequency domain, calculated using the Fast Field Propagation code, with average meteorological profiles used as input. These profiles are determined from the meteorological data collected during the measurements. Finally, the recorded wind noise is added to the propagated signal.

Figure 4.1 shows the classification results of the algorithm, with source-receiver distance of 1000 m, in downwind (wind direction from source to microphone) and upwind (wind direction from microphone to the source) conditions. The results are calculated using approximately one and a half-hours of acoustic data, for different wind and turbulence conditions. The results are averaged, to obtain results as a function of wind speed, corresponding to the Beaufort wind speed scale.

Note the drop in performance for the average wind speed of 2 Beaufort in the left graph of figure 4.1. One of the calculated propagation filters shows a sharp dip near the main rotor frequency of the simulated type 3 helicopter. This dip results in a bias in the detected main rotor frequency. This causes errors in the type classification. In real conditions this could occur as well, although variation in the atmospheric conditions and the distance of the helicopter would result in varying propagation conditions. The biased detection would seldomly occur.

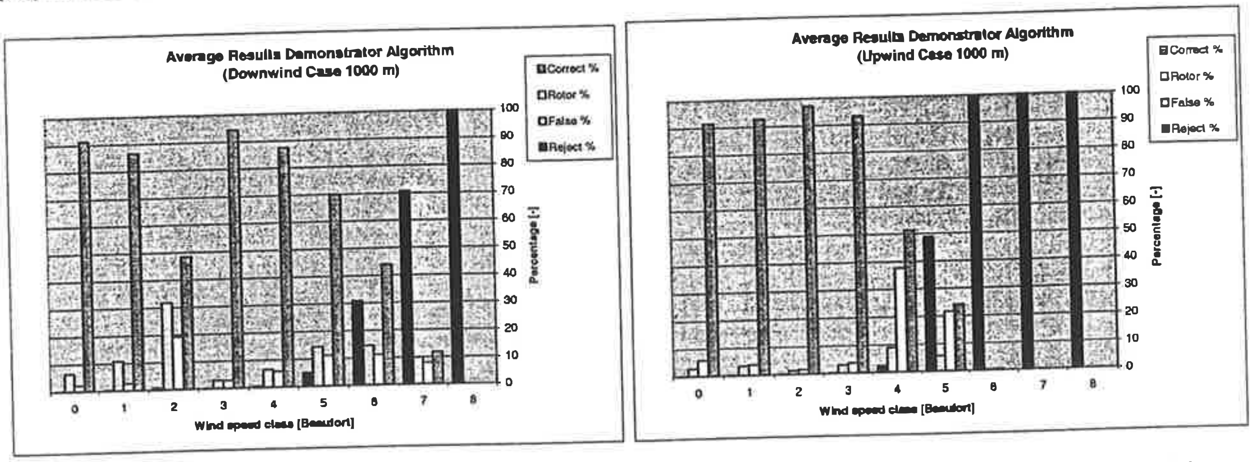


Figure 4.1: Left: Results at 1000 m downwind from the source, averaged for different wind speeds. Right: Results at 1000 m upwind from the source, averaged for different wind speeds.

To show the ability to reject wind noise signals, the acoustic data gathered in different wind conditions was submitted to the demonstrator algorithm. In this case the data was submitted to the algorithm as recorded, without the addition of the simulated helicopter noise or the application of the propagation filter.

Here we show the results on data recorded at an average wind speed of 0 Beaufort (figure 4.2), and an average wind speed of 7 Beaufort (figure 4.3). From these figures we see that the algorithm successfully rejects all sequences. The data shown in figure 4.2- 4.3 is merely an example of the performance on data that does not contain helicopter noise. The algorithm is tuned in such a way that it successfully rejects data that contains artillery noise, jet noise, vehicle noise and wind noise at different wind speeds.

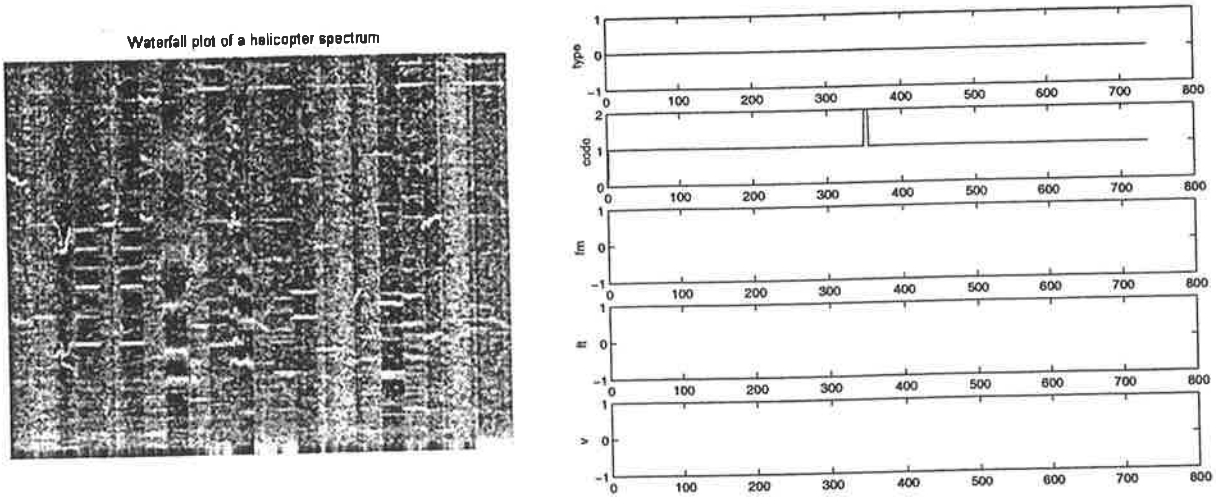


Figure 4.2: Left: Processed spectra of wind noise data at an average wind speed of 0 Beaufort, 23 sequences of 32 s data. Right: Classification results on the data.

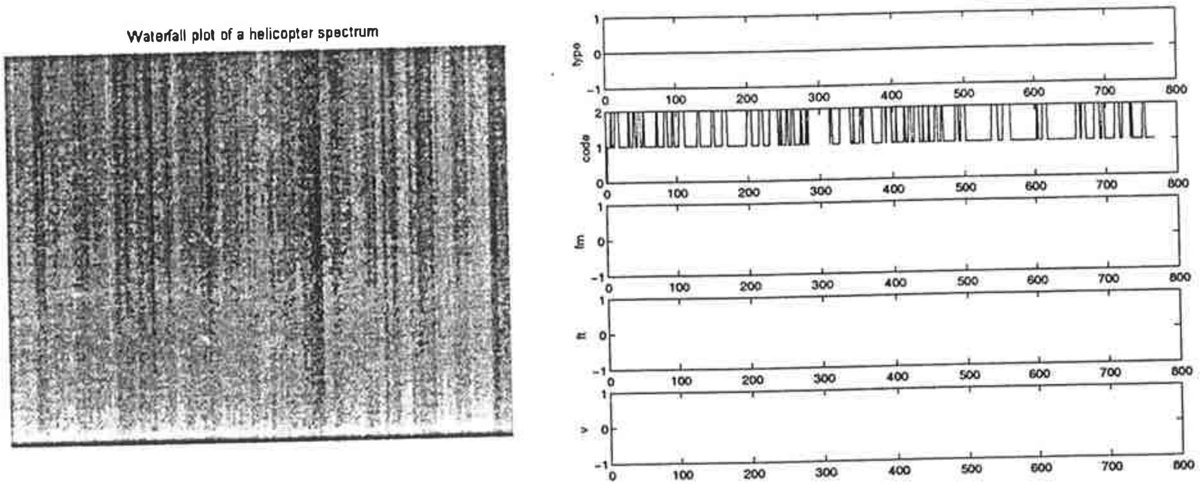


Figure 4.3: Left: Processed spectra of wind noise data with at an average wind speed of 7 Beaufort, 24 sequences of 32 s data. Right: Classification results on the data.

5. RESULTS OF FIELD TRIALS

Field trials to test the demonstrator on different types of helicopters and aircraft were held at two airfields in the Netherlands. The test team did not direct the flights; we were allowed to be present during normal training operations. The figures below are some examples of the performance of the demonstrator for different targets.
Figure 5.1 contains data of a helicopter with load, starting behind a treeline at approximately 1600 m. The helicopter passed the measurement position at approximately 500 m, to return in a wide circle back to its starting point.

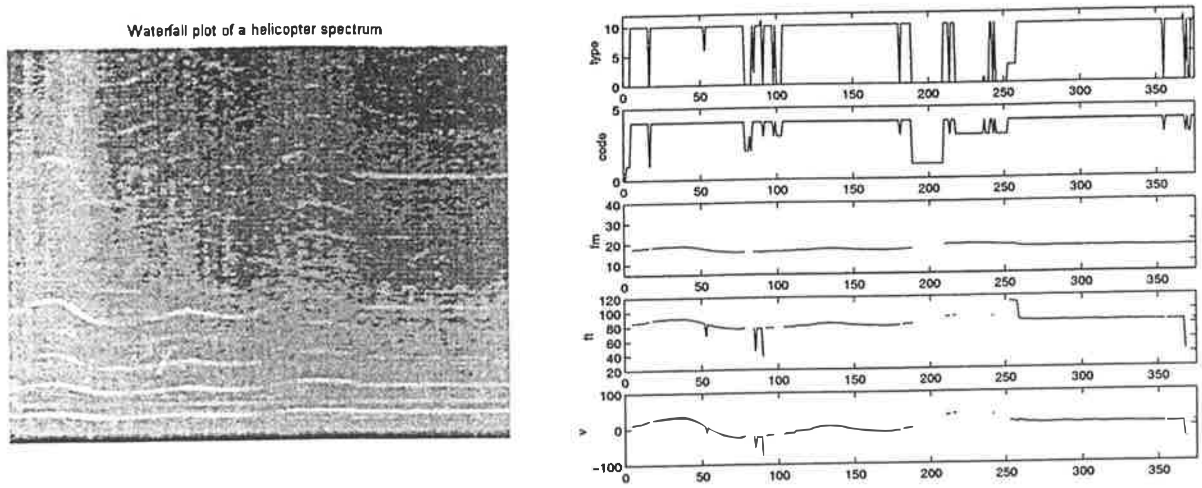


Figure 5.1: Left: Time frequency distribution of the passage of helicopter type 10. Horizontal: time axis (0-370s), Vertical: frequency axis. Right: Classification results on the data. From top to bottom: helicopter type, classification code, main rotor frequency, tail rotor frequency and helicopter speed.

Figure 5.2 contains data of multiple helicopters, two of type 10, one of type 9, one unknown and the landing of a fixed wing aircraft. The classification results in figure 5.2 show that in most cases the strongest signal is classified, with some false classifications.

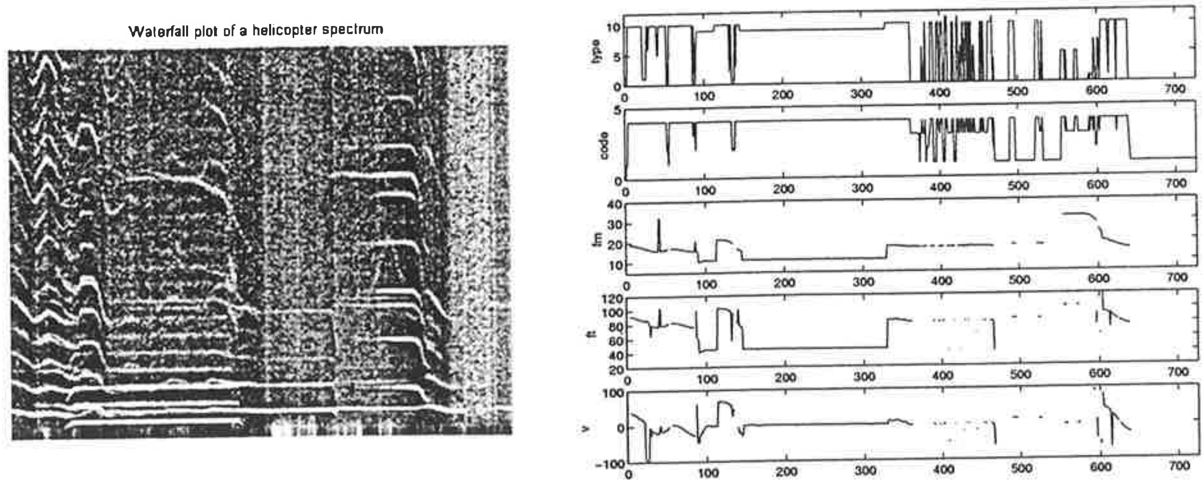


Figure 5.2: Time frequency distribution of multiple helicopters, two of type 10, one of type 9, one unknown and the landing of a fixed wing aircraft. Horizontal: time axis (0-725s), Vertical: frequency axis. Right: Classification results on the data, from top to bottom: helicopter type, classification code, main rotor frequency, tail rotor frequency and helicopter speed.

Figure 5.3 is an example of the performance of the demonstrator for two targets of the same type. It contains data of two helicopters; both type 7, from rotor startup to hover and take-off. If inspected in more detail, we see one helicopter leaving, and an additional helicopter starting up and leaving as well.

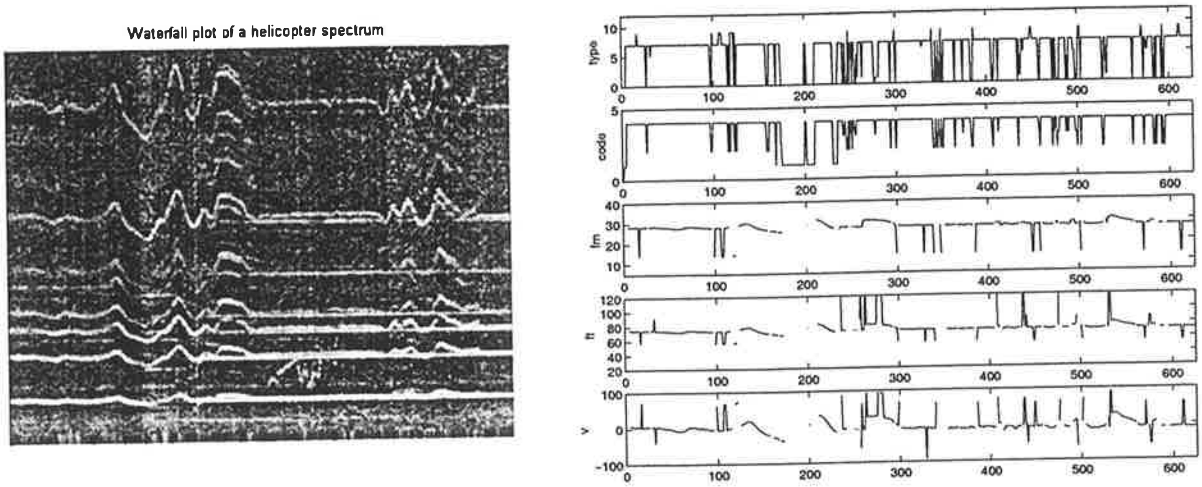


Figure 5.3: Left: Time frequency distribution of multiple helicopters, two type 7. Horizontal: time axis (0-625s), Vertical: frequency axis. Right: Classification results on the data, from top to bottom: helicopter type, classification code, main rotor frequency, tail rotor frequency and helicopter speed.

The general conclusion based on the results of the field trails is that the demonstrator algorithm was able to classify the types present in the database, at distances varying from 500 to 2000 m, depending on the type, wind direction and flight characteristics (hover, taxi, take-off). Helicopter type 10 was not in our database prior to the measurements. After a short measurement this type could be added to the database, after which the demonstrator could also detect and classify this type as well. With the current parameter settings of the demonstrator algorithm, little false alarms are exhibited if no targets are present.

6. CONCLUSIONS AND RECOMMENDATIONS

The possibility to detect and classify helicopters automatically has been shown, using data gathered in measurement campaigns, and data gathered during recent field trials. The possibility to add helicopters to the classifier database has also been shown during the field trails. The demonstrator exhibits a low false alarm rate. If helicopters and fixed wing aircraft are present at the same time, this causes occasional classifications of the wrong helicopter type. However, most of the time the helicopter is classified correctly. If more than one helicopter is present, the one that produces the strongest signal at the microphone position is detected and classified. Signals of approximately equal strength cause the classification output to switch between both types. This can be avoided, if the algorithm is adapted to look for more than one helicopter. With the techniques currently used in the detection and classification process this is possible. It is advisable to include such a possibility in a future prototype, provided the military need for such an option exists. The algorithms that were developed for the demonstrator provide a well-documented start for prototype development. The demonstrator itself will be used for further research, starting with the detection and classification of fixed wing aircraft and UAV's.

7. ACKNOWLEDGEMENTS

The research is funded by the School of Military Intelligence of the Royal Netherlands Army. The field trails were performed with the enthousiastic support of the personnel of both airfields.

8. REFERENCES

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