Interference Measurements in a Rail Environment

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BIOGRAPHY

Dr. Alexander Steingass received his Bachelor from University of Ulm. He achieved the Master and Ph.D. degree from University of Essen, Germany in 1997 and 2002, respectively. Since 1997, he is with the German Aerospace Centre (DLR) as a scientific staff member and already participated at the ESA Signal Design Study 1997-1999, the DLR NAVSIM, Heywow and GALILEONAV Project, the ESA Critical Environment Study and the EU FP6 ANASTASIA Project. He is an expert within the field of GNSS signal structures, GNSS simulation, merging of GNSS and communication systems, aeronautical GNSS and multipath measuring methodology. He holds 36 granted patents with additional 17 pending and received the ION Best Presentation Award in 2003 and the EEEFCOM Innovation Award in 2007.

Christian Weber graduated from Technical University of Munich, receiving his Diploma degree in 2004. He worked at Fraunhofer-Gesellschaft as a research fellow in the field of communication systems. Since 2005 Christian Weber is with the German Aerospace Centre (DLR) focusing on interference effects on GNSS receivers. He is involved in various European, national and DLR projects both as coordinator and as technical contributor of work packages as well as in interference measurement campaigns for ESA.
He is leading the interference activities for safety of life applications in the Institute of Communications and Navigation of DLR.

Thomas Jost received a Diploma degree (FH) 2001 in Electrical Engineering from the Applied University of Wiesbaden, Germany and Diploma degree 2003 in Electrical Engineering and Information Technology from Technical University of Darmstadt, Germany. From 2003 to 2006 he held a research assistant position at Signal Processing Group at TU Darmstadt. Since 2006 he is as member of the scientific staff of the Institute of Communications and Navigation at the German Aerospace Center.

ABSTRACT

It is hard to beat an established system. With this conclusion Europe started to built up the new independent navigation system GALILEO. The established GPS system has to be outperformed to guarantee a good market position. In terms of navigation systems this means clearly: More bandwidth, new frequency bands and new services. But bandwidth was rare and many frequency bands are occupied. The only solution was a share with other services such as DME services. The remaining question was: How silent are the new frequency bands? Interference problems with GPS made clear: Even the well established L1 band might not be as quiet as assumed.
Therefore the German Aerospace Centre (DLR) carried out a measurement campaign in the GJU funded GIRASOLE project and performed a measurement campaign in rail, maritime and land mobile environments. The huge amount of data was pre processed to extract the interferers out of the sampled signals. The interference was classified by periodogram estimations and DBSCAN clustering. The result provides a valuable preview what GALILEO will be faced with when the system will be operational.

INTRODUCTION

This work is structured as follows:
The next chapter gives a detailed view on the measurement campaign that was carried out by DLR in 2006. The data acquired during this campaign builds the basis for this work.
A section follows explaining the methodology of detection that was used for automatic decision whether interference was present in noise or not, accompanied by a short explanation of the used clustering scheme that resembles the first step in direction of automatic parameterisation and categorisation.
In the results section, exemplary graphs are shown for selected illustrative examples of data demonstrating the automatic and stepwise gain of information from raw data

to an interference cluster ready for automatic parameterisation.
Finally, the authors' approach to future work will be outlined.

MEASUREMENT CAMPAIGN

In 2006 DLR carried out a measurement campaign to achieve a clear overview about the interference situation for rail and maritime applications. For this purpose we used a measurement vehicle equipped with an Agilent 4443A spectrum analyser to measure these environments. The measurement equipment was integrated into a measurement van provided by ESA (see Figure 1).

Figure 1: Measurement equipment provided by ESA and DLR.

During the recording the spectrum analyser can only write to its built in memory and can therefore only record some seconds continuously at the relevant bandwidths of 41MHz. After the recording the measures signal samples need to transferred to a hard disk which consumes a lot of time. Therefore we took only signal snapshots of 25 ms and repeated this sampling in all navigation frequency bands periodically within 2 minutes. The Frequency bands being measured had been:

- E5/L5 +L2: 1146-1238MHz
- E6: 1260-1300MHz
- E1-L1-E2: 1555-1596MHz.

1a) Rail measurements – train ride through Germany

In this part of the experiment we mounted the measurement vehicle together with the receiving antenna on a motorail train which was then moved 800 km through Germany (Munich – Hamburg and backwards).

Figure 2: Measurement setup for rail measurements

Figure 2 shows the antenna (white hat) mounted on the motorail train and the blue measurement vehicle.

1b) Rail measurements – coastal train ride

To evaluate the interference situation in a costal area we performed measurements between Westerland (Sylt) and Niebuell (Germany). We measured all Galileo bands on 6 train rides with a individual recording length of 25 ms each.

1b) Rail measurements – trains passing by

In this part of the measurement campaign we used the spectrum analyser to record the signal at maximum length. The signal block of 2.3s is foreseen to give a indication of the interference of the moving train including the overhead contact line. These measurements have been taken on a rural site that showed minimal interference to be able to determine the impact of the train.

1c) Rail measurements - central station

For these measurements we placed the measurement vehicle on a bridge above the rail tracks of Munich central station (see Figure 3). We recorded signals in all Galileo band with a length of 2.3s. In this region we have seen a lot of interferers being present.

Figure 3: Measurement antenna at Munich Hackerbruecke

1d) Measurements in a railroad shunting yard

GNSS for rail logistic applications is a wide working field in the future. Therefore we have measured in the logistical hot spots of these systems: The railroad shunting yards in Karlsfeld (near Munich) and Maschen (near Hamburg). Those shunting yards are the biggest shunting yards in Germany. For a proper recording of the situation we logged the interference signals for 2.3s in all frequency bands (see Figure 4).

Figure 4:Measurements on the German shunting yards

1e) Railroad power switches

At the side of the railroad tracks high voltage power switches are often located (see Figure 5). Therefore we performed measurements close to a 110 kV 16 2/3 Hz power switch that switched off a load of 50 MW. We were astonished that we received even in L-Band an interference peak resulting from the electric arc inside the switch.

Figure 5: Railroad power switching site

1f) Railroad frequency transformers

The public electricity network (50 Hz) and the railroad electricity network (16 2/3 Hz) are coupled by frequency converter stations. Since in the future these stations are placed close to the rail tracks to ensure a local supply these stations are interesting in terms of interference. Therefore we measured the interference in all bands in the largest frequency transformer station in Germany in Karlsfeld.

2) Maritime measurements

Beside the rail measurements the campaign covered as well measurements in the maritime environment

2a) Offshore measurements

To evaluate the situation on the sea surface we mounted the measurement antenna on the deck of a car ferry between Rømø (Danmark) and Sylt (Germany). Figure 6 shows the antenna on the ferry.

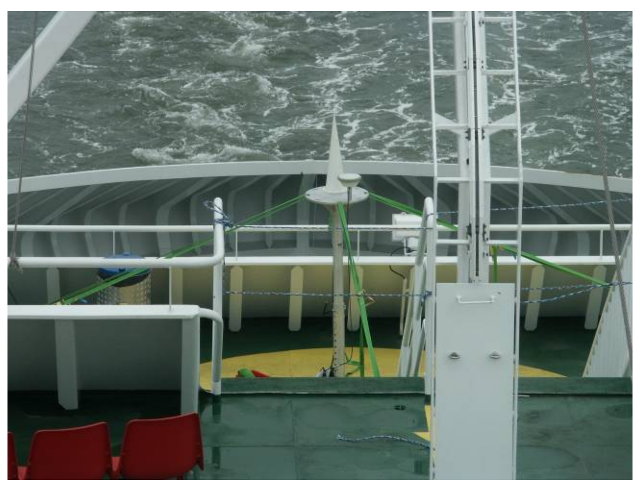

Figure 6: Maritime measurement setup

2b) Shoreline measurements

On the island of Sylt we placed the antenna on the shoreline and recorded 25ms signal blocks to evaluate the coastal situation (see Figure 7).

Figure 7: Coastal measurement setup

2c) Harbour measurements

Another logistical hot spot are cargo areas in harbours. Therefore we performed measurements in Hamburg harbour (Germany) beside the container terminals and on a vessel being pulled through the harbour (see Figure 8).

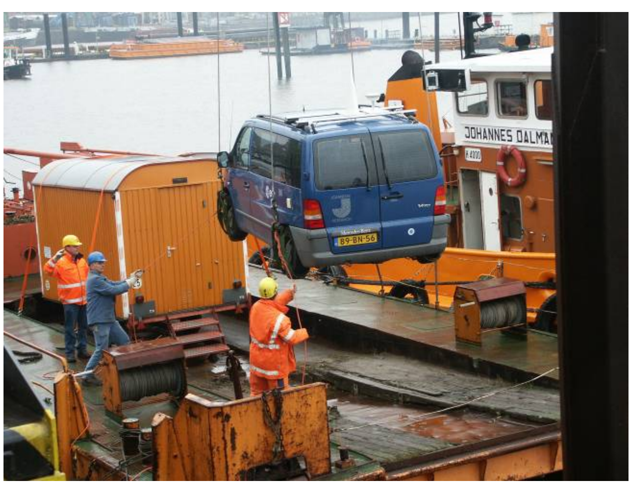

Figure 8: Harbour measurements setup preparation (the measurement vehicle was lifted onto a vessel)

The data that has been recorded during the measurement campaign provides a huge amount of interesting interference sources. In all relevant frequency bands, unexpected interference was visible at some time of the campaign. In order to learn more about these interferences, we need to detect and categorise them automatically. This is due to the big amount of data that leaves a manual approach of evaluation non-realisable. Therefore, we implemented an detection and clustering algorithm that is adapted to our needs and can build the basis for our future evaluation work on these recorded data sets.

DETECTION AND CLUSTERING

As described, datasets of approximately 25ms where sampled every 2min for each of the four upcoming Galileo navigation bands. This resulted in a total of 3407 sets. Out of the datasets 55% showed a sign of man-made signals called interference later on.

L1	24%
E6	39%
E5a	99%
E5b	56%

Table 1: Percentage of detected data sets corrupted by interference signals.

Table 1 gives a more detailed view on the percentage of sets corrupted by interfering signals per band. Because of the large amount of data, manual modelling and investigation as presented in [5] is not an option and an automatic algorithm was used to first identify sets including interference and second extracting information about signals. In order to detect peaks in time, i.e. pulses, as well as continuous wave interferers analysis was continued using the spectrogram as a time-frequency representation of the dataset which is based on a normalised squared version of the short-time-Fourier transform (STFT). As each of the time slices is a periodogram estimate $I_{XX}^{N}(e^{j\omega})$, its distribution in the absence of interference, i.e. in the white noise case H_0 [1] is

$$I_{XX}^{N}(e^{j\omega})\Big| H_0 \sim \frac{\sigma^2}{2}\chi_2^2,$$

where σ^2 denotes the variance of the background noise which was estimated from the datasets known to be free of interference. In a straight forward manner p-values for each point in the time-frequency plane could be calculated and combined to an overall test by using a multiple hypothesis testing (MHT) scheme. In our framework we used the algorithm described in [2] which strongly controls the family wise error (FWE) rate and is an extended version of Simes' MHT procedure [3]. We used a confidence level of 1% for the data detection scheme with the equivalent power as shown in Table 2.

Munich-Hamburg	L1	-160.622 dB(mW/Hz)
	E6	-160.807 dB(mW/Hz)
	E5a	-160.812 dB(mW/Hz)
	E5b	-160.811 dB(mW/Hz)
Hamburg-Munich	L1	-158.540 dB(mW/Hz)
	E6	-158.598 dB(mW/Hz)
	E5a	-158.700 dB(mW/Hz)
	E5b	-158.613 dB(mW/Hz)

Table 2: Threshold corresponding to 1% of false alarm rate

After detection we could exclude 45% of the data sets as containing only white noise.
The datasets decided to include interference were further processed to gain statistical parameters of the interference signals. As all different types of man-made signals may be expected a non-parametric method for signal parameter extraction had to be used. Based on the spectrogram all points with a corresponding p-value of less or equal to 0.1% are used inside a clustering algorithm to estimate time and frequency dimensions of interfering signals as well as the number of signals. The small level of 0.1% was needed because of computational burden. For clustering, the DBSCAN algorithm [4] was used. As parameters for DBSCAN the minimum number of points building a cluster was set to two and the Eps-neighbourhood according to the heuristic algorithm presented in [4] with a false alarm rate for detection and acceptance of a cluster of 1%. After clustering interference signals could visually be seen in clusters, but also a lot of false clusters occurred because of the small minimum number of points per cluster which is necessary to archive sharp edges of clusters. Heuristically we removed all clusters with less than ten points in the time-frequency plane as being marginal. All surviving clusters were tested again by the MHT procedure as described above in a rectangular time-frequency contour defined by the outer points belonging to the cluster.

RESULTS

In order to achieve the goal of automatic characterisation and parameterisation of interference, we followed the approach of using the time variant power spectrum within the frequency band of interest as the basis of our signal processing. This section will illustrate our first results within this field and the performance we were able to achieve.
We will now present four selected datasets as examples for performance evaluation. For each dataset, four illustrations will be shown and further explained:
First, the spectrogram resembles the received power density versus time and frequency and gives a first impression what have been recorded. Since the GNSS signal is burrowed inside the noise, the picture would be completely blue in case of no occurring interference. The noise level in our case lies at roughly -168dB(mW/Hz), periodogram windows have a length of 100µs that leads to a frequency resolution of 10kHz.
The second picture resembles the result after a first run of the clustering algorithm described in short in the "Detection and Clustering" section.
One additional picture shows the clustering results after applying our plausibility checks also explained within the "Detection and Clustering" section. This step usually leads to a significant reduction of "noise clusters".
The last picture in this line presents a satellite camera view on the measurement location produced with a Google Earth™ Professional version. This allows to characterise the surrounding environment and watch out for special appearances as for example rivers, harbours, stations, roads and buildings.

The first dataset was recorded on the E5a frequency band near Wuerzburg, Germany at latitude 49.8017 longitude 9.8932. The spectrogram shows 6 narrow interference lines at different frequencies and one more broadband (ca. 1.5 MHz) interference with lower spectral density at a lower frequency that are all relatively time invariant. Power density is given in dB(mW/Hz), frequency from bottom to top represents the frequency relative to the middle frequency and time from left to right represents the time into the recording in seconds. This applies to all following recording graphs.

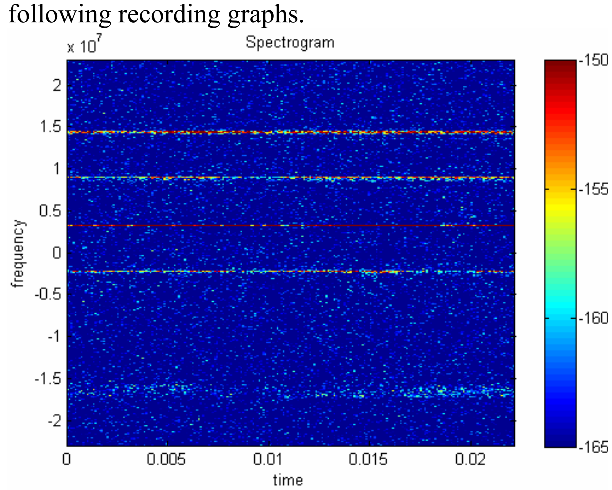

Figure 9: Spectrogram of dataset "MH E5a 173" showing several narrowband interferences and one broadband interference at roughly -1.5 MHz. Power density in dB(mW/Hz). Frequency from bottom to top represents the frequency relative to the middle frequency. Time from left to right represents the time into the recording in seconds.

First clustering produces 8 strong clusters and several minor clusters that are triggered by noise and is shown in the following picture.

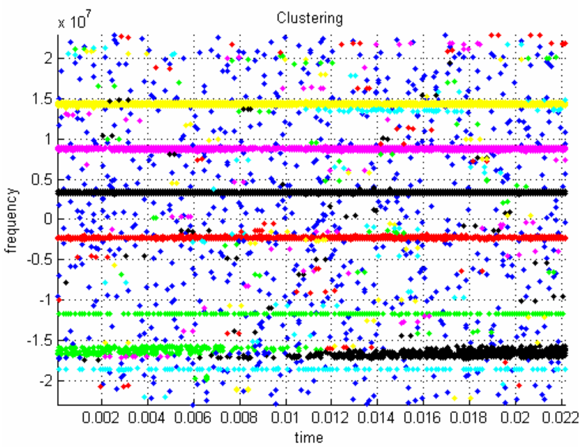

Figure 10: Result of dataset "MH E5a 173" for first clustering run.

Second clustering run with removal of noise triggered clusters leads to the 8 strong clusters of which 2 are designated to the same interference source. At this stage, characterization of interference sources at an automatic level is possible, providing information about centre frequency, bandwidth and type.

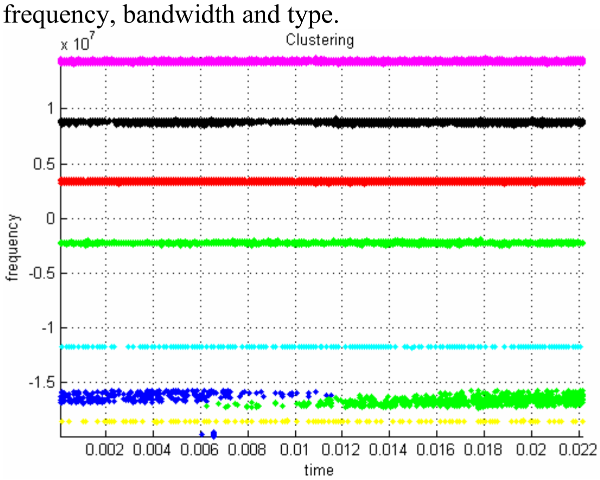

Figure 11: Result of dataset "MH E5a 173" after noise clusters removal.

The area where this interference source was recorded is near the main station of Wuerzburg, Germany. In the near vicinity, the river Main accompanies the rail road that is used for shipping. A major harbour is located nearby.

Figure 12: Local area of dataset "MH E5a 173".

The second dataset was recorded near Hamburg at frequency band E6. The spectrogram shows two broadband interference sources, two clearly visible narrow band interferences and several minor disturbances.

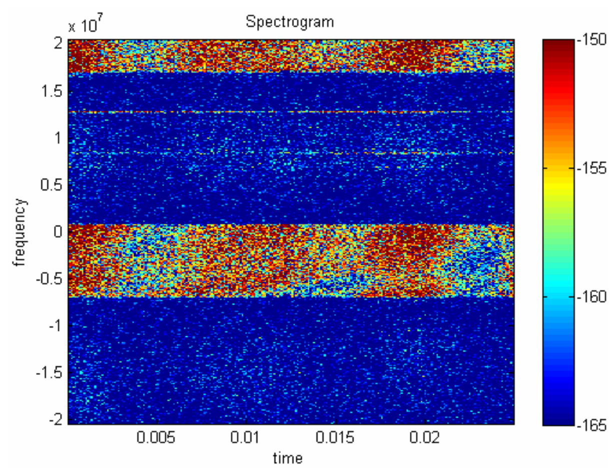

Figure 13: Spectrogram of dataset "MH E6 392".

Applying the clustering algorithm leads to the following result. The algorithm correctly recognised the two broadband transmissions but produced quite a lot noise clusters.

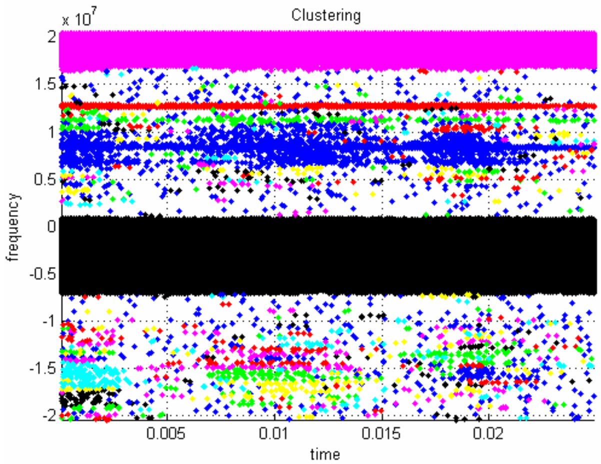

Figure 14: Clustering of dataset recording "MH E6 392" containing noise clusters.

After removing the noise clusters, the two broadband transmissions remain together with some narrowband interference sources and a third broadband interference that was almost buried in noise.

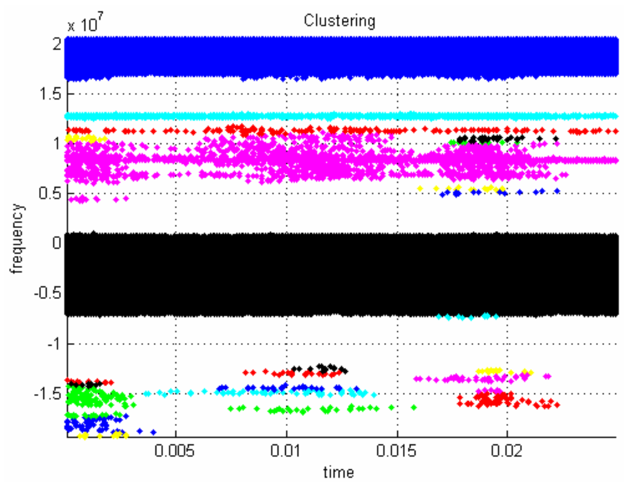

Figure 15: Clustering of dataset recording "MH E6 392" after removal of noise clusters.

The location at 53.4106 latitude and 10.014 longitude can be characterised to be rural in general with the only exception that one of Europe's biggest railroad shunting yard is located nearby at Maschen.

Figure 16: Position of dataset recording "MH E6 392" near Maschen.

The next dataset's origin is near the Munich main railroad station. The spectrogram shows several interfering transmissions in frequency band E5a of roughly 1.5MHz bandwidth.

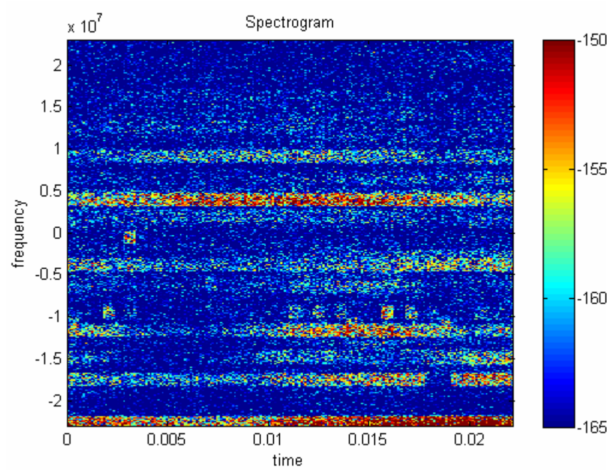

Figure 17: Spectrogram of dataset "MH E5a 39".

The clustering algorithm correctly detects interference but has problems distinguishing transmissions on different frequencies and forms a united cluster.

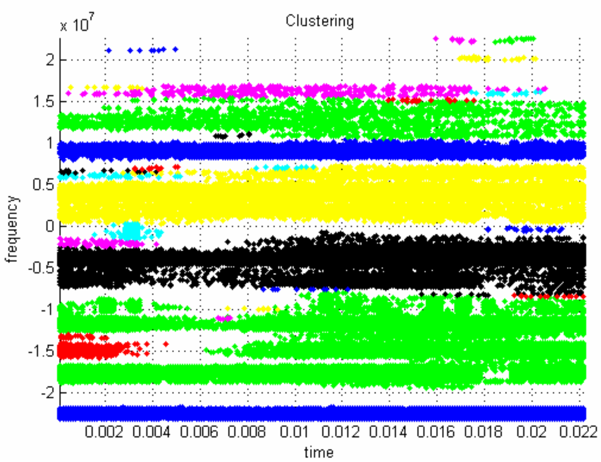

Figure 18: Clustering after removing noise clusters for dataset "MH E5a 39".

The location at latitude 48.1412 and 11.5476 longitude is near the Munich main train station and directly next to the control tower and the Bavarian broadcast channel building.

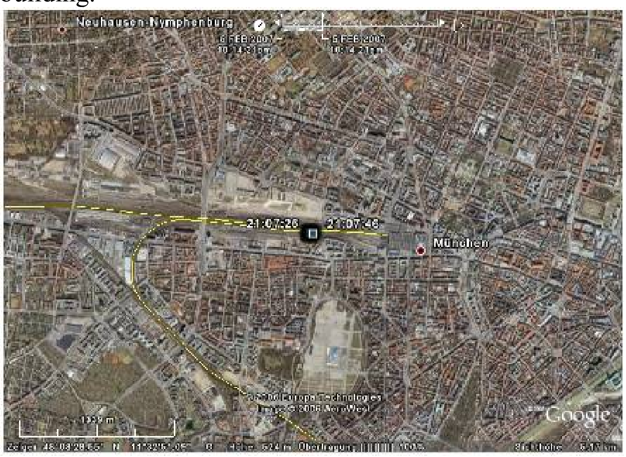

Figure 19: Satellite view on "MH E5a 39" recording environment showing Munich main train station.

Our last example presents two pulsed interference formations from recording "HM E5a 13":

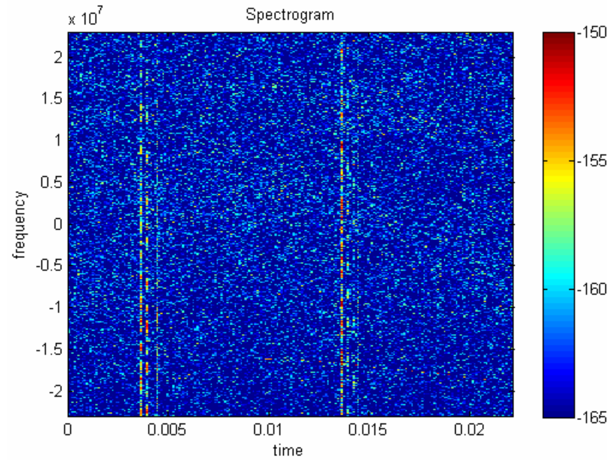

Figure 20: Spectrogram of recording "HM E5a 13" showing two occurrences of pulsed interference.

The clustering creates several clusters for each pulsed interference and therefore more than really present. Additionally, two narrow band interferences are detected and clustered that are hardly visible from the spectrogram. An automatic characterisation of this interference sources would not come to correct results. Therefore, advanced techniques for cluster merging and dividing are needed.

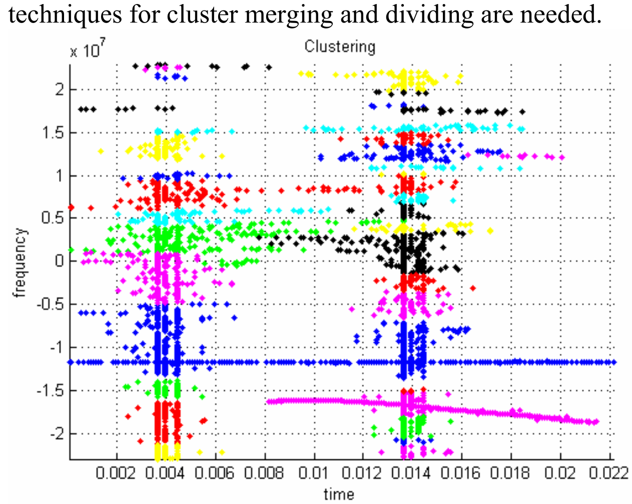

Figure 21: Clustering view of recording "HM E5a 13" after removing noise clusters.

The location at latitude 53.5575 and longitude 9.9357 represents urban environment near the Hamburg main train station and near the Hamburg Harbour, one of Europe's biggest harbours. Therefore, a lot of different communication and radar systems can be expected in this environment.

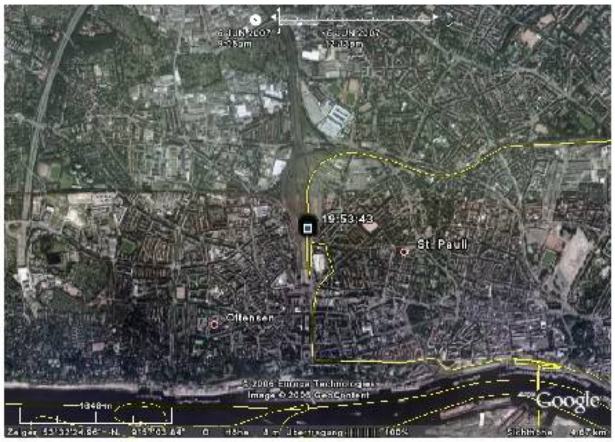

Figure 22: Local environment of recording "HM E5a 13" was Hamburg near the main train station.

CONCLUSIONS AND OUTLOOK

This work provides first results on applying a clustering algorithm to the problem of automatic interference characterization. Using a multiple hypothesis test for detection of signals, clustering enables automatic information extraction. It works well with signals that are strictly separated in frequency or time domain. Some effort has to be invested into intelligent algorithms for merging and dividing existing clusters. As a next step, individual interference sources can be automatically categorized into pulse, non-pulsed, narrow band and broadband with the corresponding characteristics as pulse width, duty cycle, bandwidth and middle frequency. Using this knowledge, an intelligent receiver can decide what counter measure would be the best solution in mitigation the specific interference source. One solution could be the application of adaptive beamsteering [6].

ACKNOWLEDGMENTS

The authors highly appreciate the contribution of Cecil Schandorf to the data evaluation and Andreas Lehner and Werner Rox to the measurement campaign itself.

The measurement campaign was carried out within the frame of the GJU project Girasole in 2006.

Furthermore, we would like to thank ESA-ESTEC and Joanneum Research, Graz for their great support.

REFERENCES

[1] D. R. Brillinger, "Time Series data analysis and theory", Holden-Day Inc., 1981

[2] Y. Hochberg, "A sharper Bonferroni procedure for multiple tests of significance", Biometrika, 75(4), p. 800-802, 1988

[3] R. F. Brcic, "Some Aspects of Signal Processing in Heavy Tailed Noise", PhD thesis, Curtin University of Technology, 2002

[4] M. Ester, H.-P. Kriegel, J. Sander and X. Xu, „A Density-Based Algorithm for Discovering Clusters in Large Spatial Databases with Noise", Int. Conf. on Knowledge Discovery and Data Mining (KDD), 1996

[5] C. Weber, A. Konovaltsev, M. Meurer, "Investigation of Potentially Critical Interference Environments for GPS/Galileo Mass Market Receivers" in 2n Workshop on GNSS Signals & Signal Processing (GNSS Signal) 2007, ESTEC, Nordwijk, Netherlands 24.4.2007-25.4.2007

[6] De Lorenzo, David S.; Antreich, Felix; Denks, Holmer; Hornbostel, Achim; Weber, Christian; Enge, Per (2007): Testing of Adaptive Beamsteering for Interference Rejection in GNSS Receivers. In: 2007 ENC GNSS, EUGIN, ENC GNSS 2007, Genf, Schweiz, 2007-05-29 - 2007-06-01