Radiation : laboratory on beamforming

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1 Introduction

Beamforming is a technique used in telecommunications which can be used to transmit or receive signals. It consists of summing different transmission to create a radiation pattern wanted. In this laboratory, a source located in the center of the room was sending signals to eight receiver antennas on a board. To locate this source a minimum variance method combined with the MUSIC algorithm was implemented.

2 Theory

Let's consider the output of the beamformer

$$S = w^H y \tag{1}$$

The power linked to these signals is:

$$P = \left\langle |w^H y|^2 \right\rangle \tag{2}$$

To localize the source, the direction for which we have a maximum power have to be found. It is then necessary to calculate the power for every direction and then find the maximum. We can improve this technique of detection by using a minimum variance method consisting of finding the weights w such that we have a minimum output power from the beamformer. This will give sharper peaks of power. The minimum variance method can be done by using Lagrange multipliers giving the solution for the weight. This solution is:

$$w = \frac{R^{-1}e}{e^{-1}R^{-1}e} \tag{3}$$

The expression of the average power then become:

$$P^{MV} = (e^{-1}R^{-1}e)^{-1} \tag{4}$$

This method can still be improved by modifying the R^{-1} matrix with the MUSIC algorithm. In this case a new R^{-1} matrix is calculated by:

$$R^{-1} = \sum_{i=N+1}^{M} v_i v_i^H \tag{5}$$

For which we take the N dominant eigenvalues and we consider the eigenvectors v_i not related to those N eigenvalues.

The entire code was made by following this theoretical part. All the steps about how the code is made are explained in the code as commentaries.

3 Results

The following figures are the results of our implementation for 3 different tests using the music algorithm, the first one being hidden and the others being our own hand made tests. The 2 tests we have conducted were supposed to draw a 'S' and a '8'. We guessed that the hidden test is supposed to be the letter 'W'. Next to each drawing we have represented the most accurate (in term of power) measure of the position.

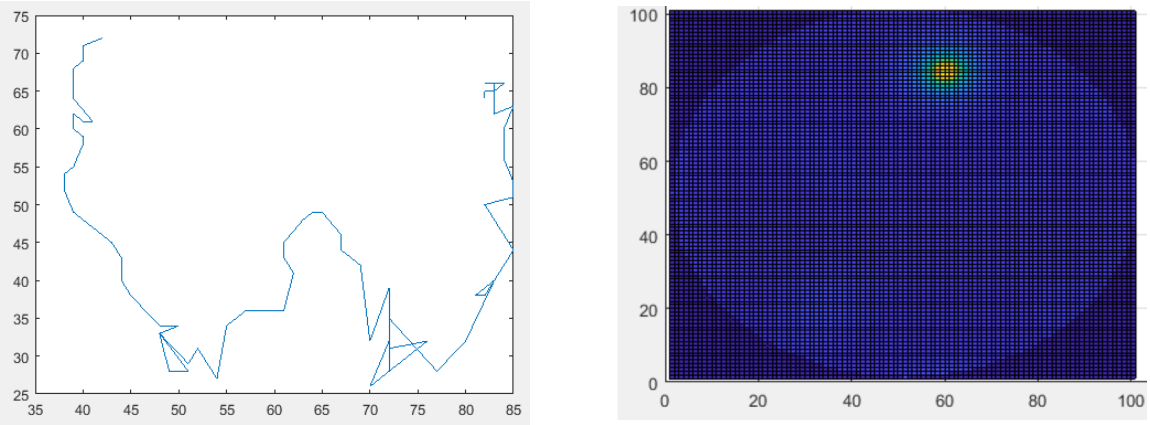

Figure 1: The figure on the left displays the hidden test using the Music algorithm, which appears to be a W, the right figure shows the best position measurement

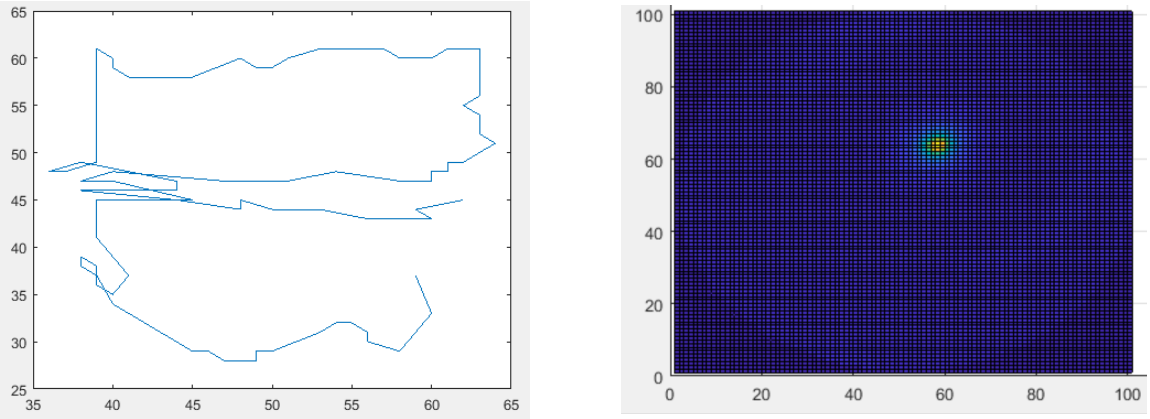

Figure 2: The figure on the left displays the hand made test using the Music algorithm, which is supposed to be a 8, the right figure shows the best position measurement

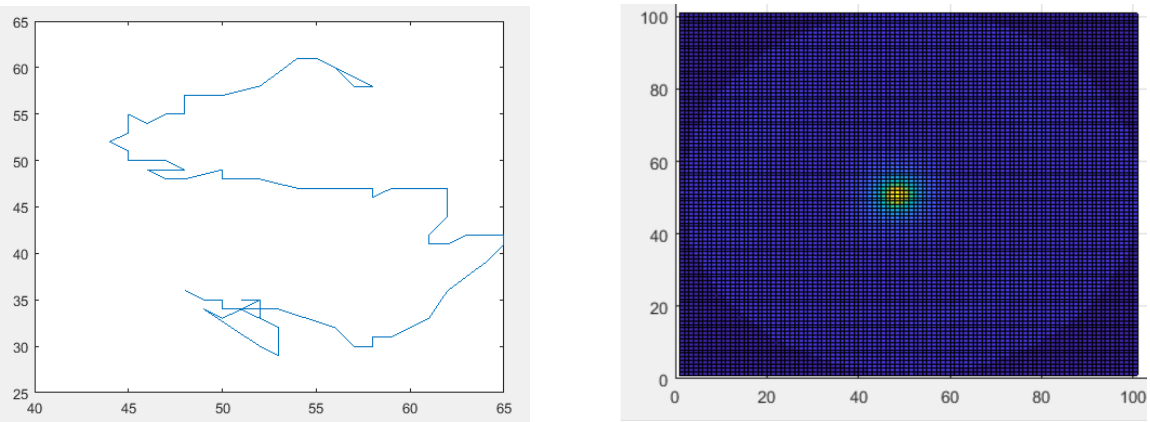

Figure 3: The figure on the left displays the hand made test using the Music algorithm, which is supposed to be a S, the right figure shows the best position measurement

Also, it is possible to see results of the simulation by not using the music algorithm and simply using the inverse matrix, as shown on the following figures.

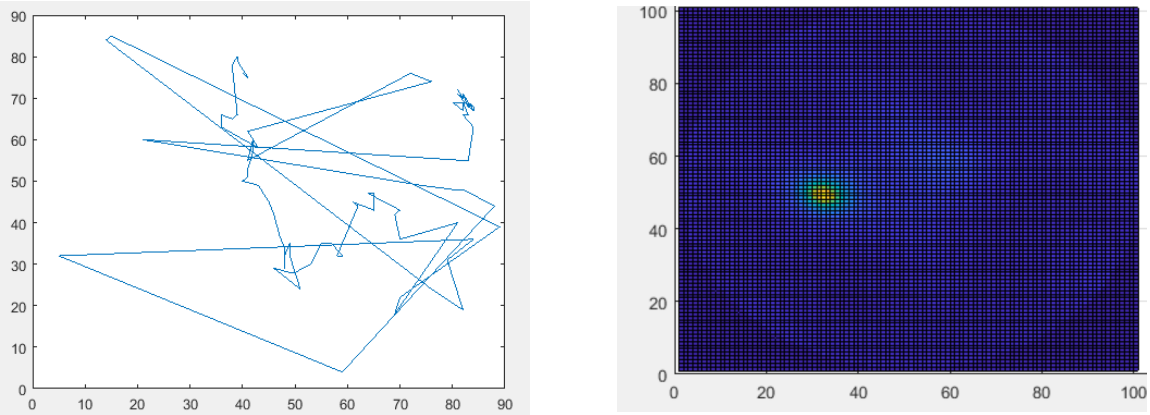

Figure 4: The figure on the left displays the hidden test without using the Music algorithm, which appears to be a W, the right figure shows the best position measurement

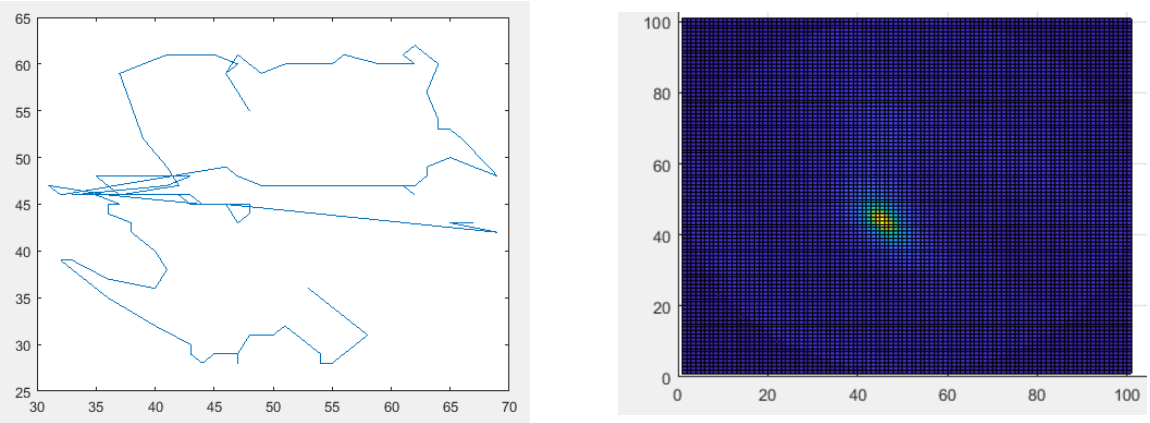

Figure 5: The figure on the left displays the hand made test without using the Music algorithm, which is supposed to be a 8, the right figure shows the best position measurement

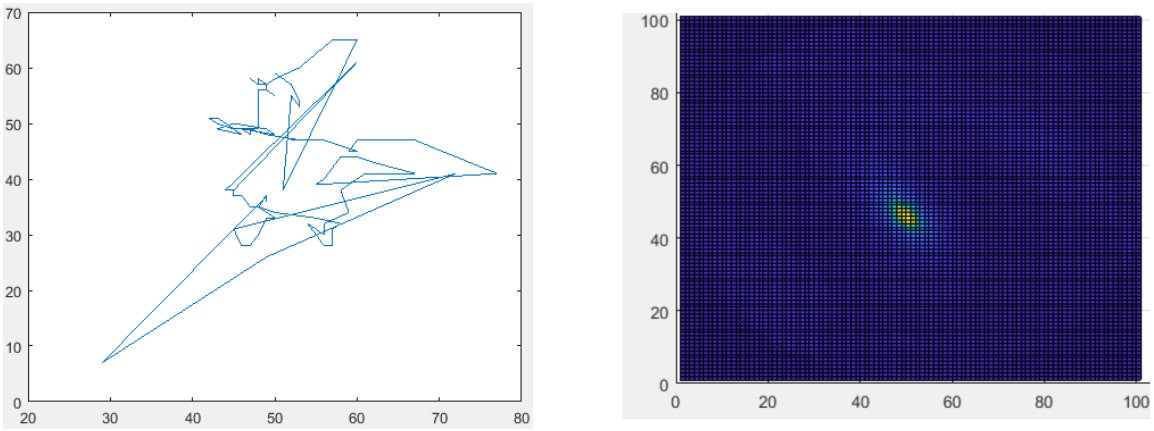

Figure 6: The figure on the left displays the hand made test using without the Music algorithm, which is supposed to be a S, the right figure shows the best position measurement

We can also see what happen on the limit of the visible domain when using the music algorithm or not.

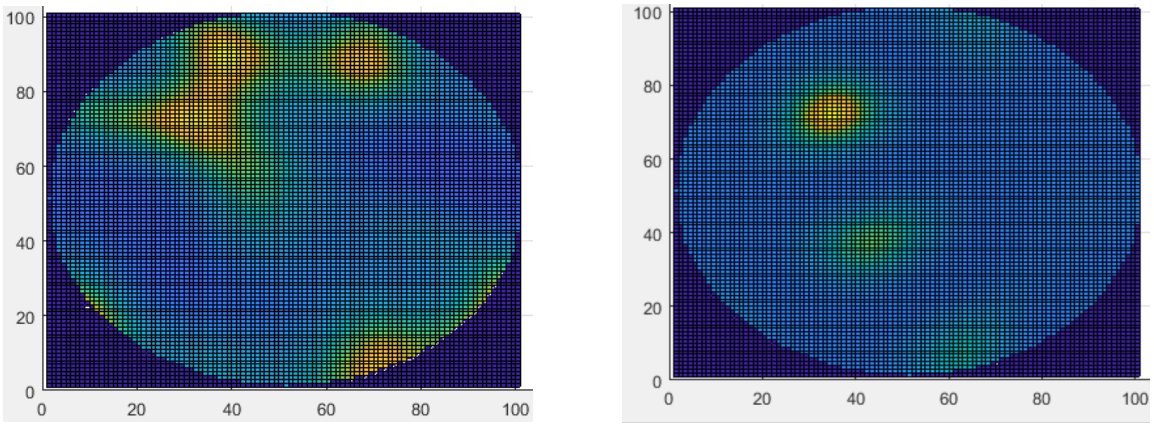

Figure 7: Both figures display a maximum near the edge of the visible domain. The left and the right show respectively result with out and with the music algorithm.

Simulations have also been made with 2 antenna in order to better assess the requirements for such device to function.

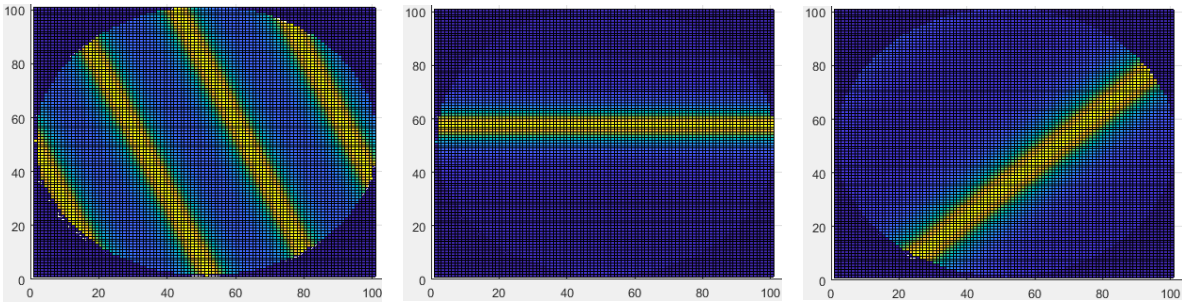

Figure 8: The very left figures is the result for 2 antennas that are placed at either site of the transmitter's position, the middle one is for two neighbouring antennas situated on top of the circular array and the right one uses two neighbouring antennas situated on the top left side of the circular array

Decreasing the number of antenna has as effect to make the Radiation pattern periodic (an infinite number of antenna would mean no repetition), thus the less antenna the more the pattern is copied periodically, which is working against our goal because it makes more possible maxima as seen on the left picture of figure 8. Moreover the period of the radiation pattern depends on $\frac{\lambda}{d}$, with d the distance between the antennas, so things gets worse for antenna that are far away from each other, that behaviour can only be seen on the left picture and not on the other 2 because they are too close.

4 Conclusion

Regarding the results, the implementation meets targets even if the precision of the positioning remains a little imprecise at times. Also as it can be expected, as the emitter get closer to a surface, reflection becomes more important and can interfere with the detection of the "main" direction which gives hectic results. Also, it noticeable that the music algorithm greatly improves upon the minimal variance method. And that the method work better the more antenna there are and the closer they are.