POLITECNICO DI MILANO

Radar Imaging:

Multipath in automotive radar imaging

Giuseppe Maria Fiorentino
Riccardo Reggiani

Description

The aim of the project is to understand the effect of multipath in automotive radar imaging. This is one of the main concerns of the automotive industry about the usage of radars on cars. The first scenario concerns the monostatic case, in which all the N antennas are transmitting and receiving orthogonal electromagnetic waves. Once analyzed the given scenario, multipath has been taken into consideration and after a mathematical analysis it has been able to deploy the matlab code. The same procedure has been repeated for the bistatic case.

1. The monostatic array, Theoretical Design

The ULA is operating at 77 GHz with maximum resolution required ρθ = 3.6 degrees. The system's required Bandwidth is B = 2 GHz and the signals transmitted are linearly modulated chirps. The received signal at each antenna will be:

$$s^{nn}_{RR}(r) = sinc(\frac{r - R^{n}(p_t)}{\rho_r}) e^{-j\frac{4pi}{\lambda}R^{n(p_t)}}$$

where $R^{N}(p_T)$ is the distance from the nth antenna to the target located in p_T .

In our model p_T has been chosen in the position with coordinates [20,50].

Expanding in Taylor series the term $R^{N}(p_T)$:

$$R^{N}(p_T) = r_0 + n\Delta_X sin(\theta)$$

Where r_0 is the distance between the antenna in the center of the array and the target, n is the antenna index, Δ_X is the spacing between antennas and $sin(\theta)$ is related to the direction of arrival of the target.

Inserting the expanded $R^{N}(p_T)$ in the exponential of $s^{nn}_{RR}(r)$ it is obtained :

$$exp\,(-\frac{j4pi*r_0}{\lambda})\; exp\,(-\frac{j2pi}{} * \frac{2\,sin(\Theta)}{\lambda})$$

in which it is identified the spatial frequency: $\frac{2\,sin(\Theta)}{\lambda}$

Applying Shannon th. the $f_S = \frac{2*2\, sin(\Theta)}{\lambda}$. In the worst case scenario Θ = 90 degrees, thus

$$f_{max} = 4 / \lambda \text{ and } \Delta_X = 1 / f_{max}.$$

Once found the Δ_X, in order to retrieve the total length of the array were needed some considerations regarding the relation between the angular resolution and the spatial frequency.

In the $R^N(p_T)$ we were able to identify the spatial frequency as $\frac{2\, sin(\Theta)}{\lambda}$. For small Θ the sin(Θ) can be approximated with the angle itself. In particular :

$$f_S = 2\,\Theta / \lambda \quad \Rightarrow \quad \Theta = \lambda f_S / 2$$

Having in mind that:

$$\rho_S = 1/ L \quad \text{and} \quad \rho_\Theta = \rho_S * \theta$$

we were able to retrieve L (length of the array) as :

$$L = f * \lambda / (2 * \rho_\theta)$$

In order to estimate at this point the DOA, it has been necessary to use Matlab.
Since the demodulated and range compressed received signal at the nth antenna was in function of the target's position, the intuiton was to implement a fft row by row of the range-compress data matrix and plot it with the *imagesc()* function. The result was:

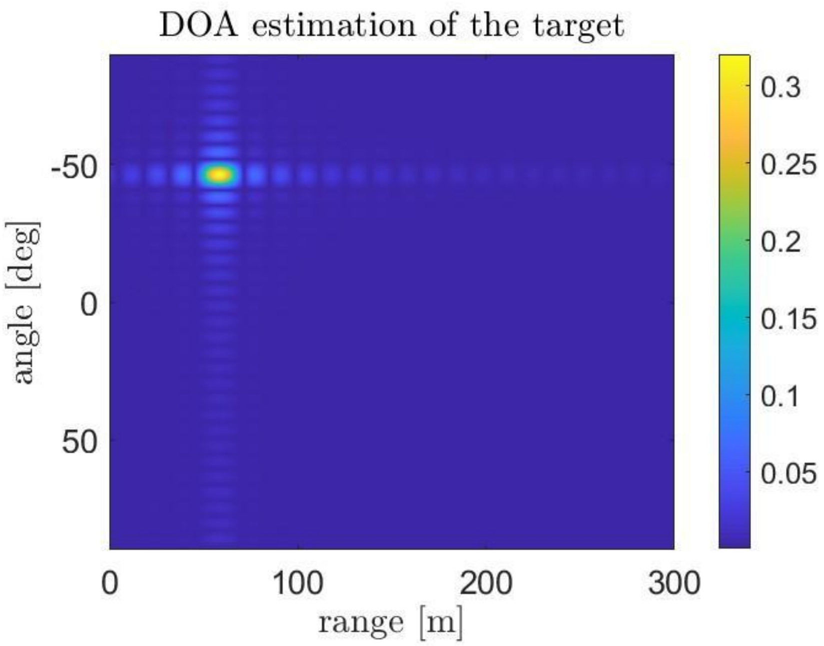

Figure 1: DOA of the estimated target

From the y-axis coordinate in which the target is visible we were able to obtain the value of the f_S from which $\theta = arcsin\,(f_s * \lambda / 2)$. Or it is possible to move from the spatial frequency y axis, directly to the degrees obtaining the following DOA angle.

1.1 MULTIPATH

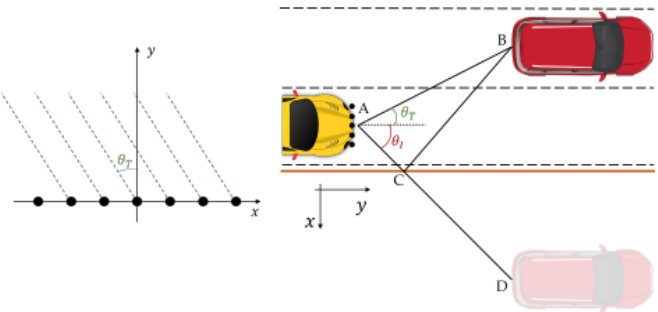

Figure 2: Geometry of the problem

An analogous procedure of the one done previously has been considered for the multipath scenario. The main difference was in the received signal :

$$s^{nn}_{RR}(x) = sinc(r - R^n(p_t) - R^n(p_I) / \rho_R) * exp(- j4pi/\lambda * (R^n(p_t) + R^n(p_i))$$

in which we can notice the additional presence of the term $R^n(p_I)$.

Through geometric considerations it has been possible to discover that the path AD is equal to the summation of the path AB + DA. Thanks to the pythagorean theorem the overall path was retrieved and substituted in the previous formula. In this way it has been possible to estimate with the data range compressed matrix the image target position and Ghost target position.

Translated in matlab code:

```
g = zeros(length(r_ax), N);
for ii = 1:N
   R = sqrt((x_s(ii)-x_t).^2 + (y_s(ii)-y_t).^2); %pitagora theorem
   R_i = sqrt((x_s(ii)-x_i).^2 + (y_s(ii)-y_i).^2); %pitagora theorem
   R_g = R + R_i;
   g(:,ii) = sinc((r_ax-R_g)/rho_R)*exp((-1j.*2*pi*R_g)/lambda);
end
```

where [x_i,y_i], are the coordinates of the image target. Once again the position of the image target has been retrieved thanks to the fft row by row of the "g matrix" :

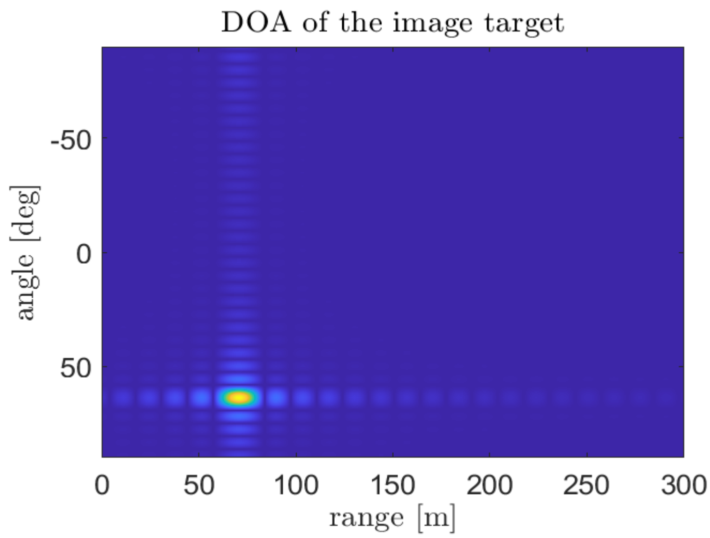

Figure 3: DOA of image target

However the main objective of this homework is to understand that multiple reflections of the electromagnetic waves can generate ghost targets in the focused image. It has been possible to understand that the ghost target was in a position between the real target and the image target:

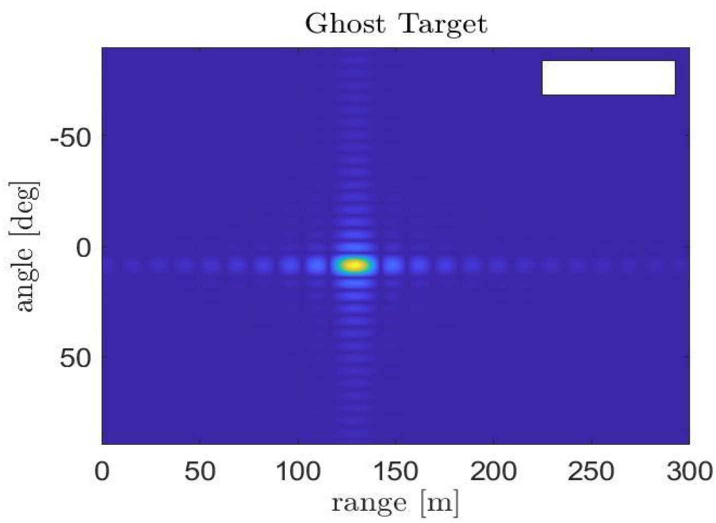

Figure 4: DOA of ghost target in monostatic configuration

2. The bistatic array

Great importance is related to the bistatic case. The boundary conditions will be the same as the monostatic. For boundary conditions it is meant the system's required bandwidth, carrier frequency and maximum resolution required.
The significant difference from above lies in the new configuration itself, instead of having all the antennas transmitting and receiving, in the bistatic array there is only one antenna transmitting and all the others (including the transmitting one) receiving.
This means that instead of having a roundtrip path like in the monstatic case there will be only one way path.
This difference in the set up brings changes in the following formulas and parameters, leading to different results from the monostatic configuration. Starting from the range compressed received signal:

$$s^{nn}_{RR}(r) = sinc(\frac{r - R^{n}(p_t)}{\rho_r})e^{-j\frac{2pi}{\lambda}R^{n(p_t)}}$$

with $R^N(p_T) = r_0 + n\Delta_X sin(\theta)$

In which the spatial frequency now is half with respect to the monostatic case.

$$f_S = \frac{2\, sin(\Theta)}{\lambda}$$

Applying, again Nyquist the antenna spacing in the bistatic case is : $\Delta_X = 1 / f_{max} = \lambda / 2$, double with respect to the monostatic scenario. Repeating the same procedure previously done it is shown that in the bistatic scenario the length of the array doubles as well:

$$L = f * \lambda / \rho_\theta$$

Nevertheless the number of antennas remain unchanged.

Implementing the system in matlab, the target position, the image target position and finally the ghost position are obtained.

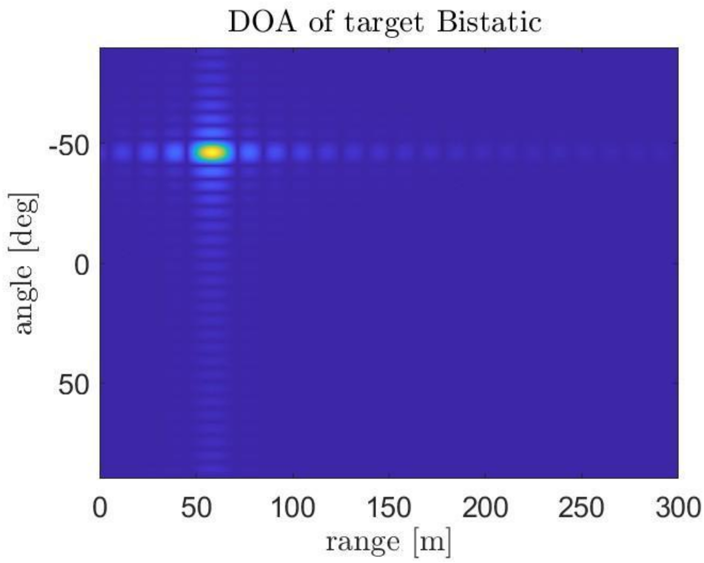

Figure 5: DOA of target in bistatic configuration

As expected, the target and image target position are in specular positions, while the ghost target has a position in between the twos.

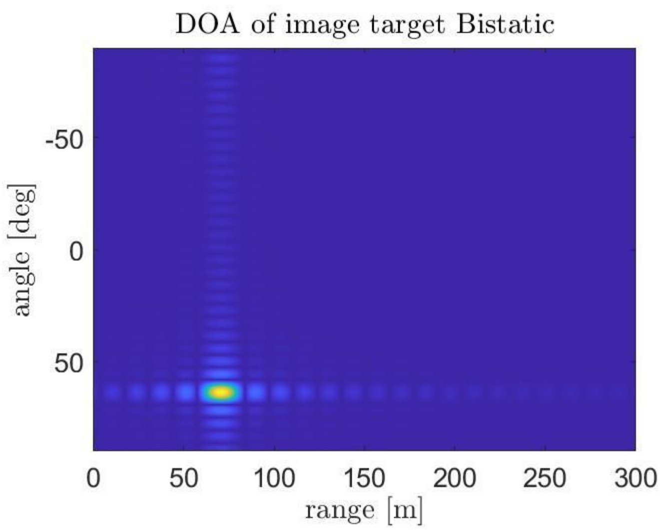

Figure 6:DOA of image target in bistatic configuration

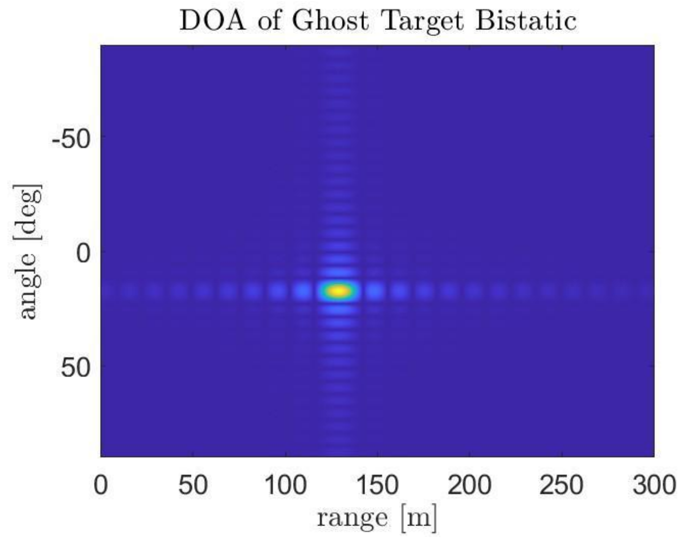

Figure 7: DOA of ghost target in bistatic configuration

CONCLUSIONS

The project allowed us to understand the effects on multipath propagation in automotive radar systems and underline the main differences when the system in use is monostatic or bistatic. The main differences between the two systems were the antenna spacing and the ghost target position. The last one was in a position between the real target and the image target. This result was expected also looking at the geometry of the system.

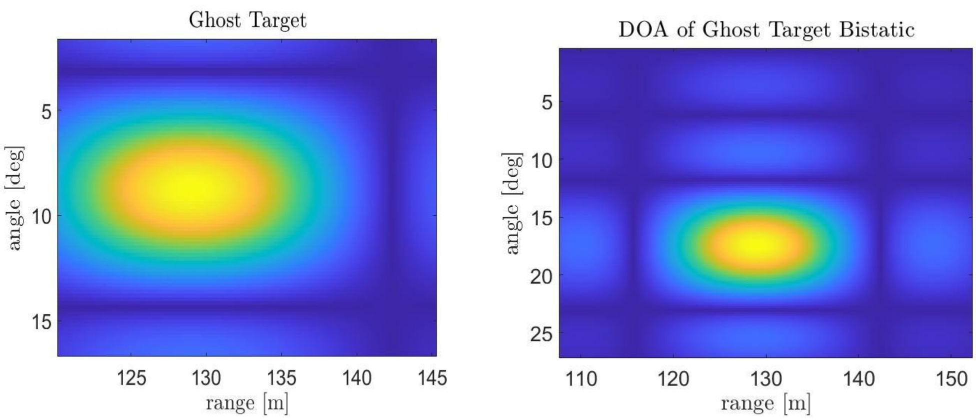

Figure 8: DOA differences between ghost target in monostatic and bistatic configuration

The DOA of the ghost target in the monostatic case has an angle between 7 and 9 degrees, while in the bistatic configuration an angle between 15 and 20.