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Evaluation of a FMCW radar as a teaching tool in the automotive and telecommunications engineering careers

Evaluación de un radar FMCW como herramienta didáctica en las carreras de Ingeniería Automotriz y Telecomunicaciones

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Abstract

In recent decades, advanced driver-assistance systems (ADAS) have evolved to be available in much of the vehicles manufactured today; it is very im-portant to keep teaching in this area up-to-date. This paper presents a frequency modulated continuous wave radar that works in the 24 GHz ISM band. The purpose of this work is to evaluate its performance and suitability to be used as a didactic tool in teach-ing in the automotive and telecommunications engi-neering careers with an emphasis on the mathematics and telecommunications subjects, under scenarios feasible to be found in university labs. For this pur-pose, the measurement scenario is described, as well as the hardware, firmware and a generic algorithm implemented in MATLAB based on fast Fourier transforms to obtain Range-Doppler maps that allow, in conjunction with the CFAR algorithm, to improve detection of objects when compared to the detection from a fixed level. The results presented demonstrate that the accuracy and precision of the radar are within the parameters for a short-range radar for vehicles, also finding a tool with great didactic potential with which students can understand today´s applications of mathematics in the field of telecommunications, especially in radars that serve ADAS systems.

Keywords: FMCW radar, Range-Doppler map, CFAR, didactic tool.

Resumen

En las últimas décadas los sistemas avanzados de asistencia al conductor (ADAS) han evolucionado hasta estar disponibles en gran parte de los vehículos fabricados hoy en día; mantener actualizada la enseñanza en esta área es de vital importancia. Este artículo presenta un radar de onda continua modulado en frecuencia que trabaja en la banda de 24 GHz ISM. El propósito es evaluar su desempeño e idoneidad para usarse como herramienta didáctica en la enseñanza en las carreras de Ingeniería Automotriz y de Telecomunicaciones con énfasis en las asignaturas de Matemáticas y Telecomunicaciones con escenarios factibles de encontrar en los laboratorios universitarios. Para ello se describe el escenario de medición, así como el *hardware*, el *firmware* y un algoritmo genérico implementado en MATLAB basado en transformadas rápidas de Fourier para obtener mapas RangeDoppler que permiten junto con el algoritmo CFAR mejorar la detección de objetos al comparar con la detección a partir de un nivel fijo. Se presentan resultados que demuestran que la exactitud y precisión del radar se encuentran dentro de los parámetros para un radar de corto alcance para vehículos, encontrándose, además, una herramienta con gran potencial didáctico, con la cual los estudiantes pueden comprender las aplicaciones que hoy tienen las matemáticas en el ámbito de las telecomunicaciones, especialmente en radares que sirven a sistemas ADAS.

Palabras clave: radar FMCW, mapa Range-Doppler, CFAR, herramienta didáctica

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1. Introduction

The radar has been traditionally employed in the military and aeronautical industries for several years, mainly due to the high complexity and the high cost associated to its use. However, with the evolution of electronics and integrated circuits (IC) it is becoming more common every day to find radars with specifications appropriate for other tasks, among which it can be mentioned the automotive industry [1]. In particular, in recent years they have been employed in advanced driver-assistance systems (ADAS) [2]. For this purpose, radar systems measure directly or indirectly the position, velocity, and even acceleration of a great variety of objects such as other vehicles, pedestrians or cyclists, thanks to the execution of different algorithms [3].

Although video cameras, ultrasound and other systems are also currently used, radars have the advantage of being little affected or unaffected by environmental conditions such as temperature, illumi-nation, dust, etc. This is why they can operate individually or together with other technologies to guar-antee the high accuracy, precision, reliability and adaptability required by ADAS systems [4].

Besides objects detection, radars have other applications such as the identification of physical condi-tions, in particular the friction coefficient of a road. This can be employed to issue alerts or take actions to avoid accidents, especially under adverse conditions such as rain or ice [5], [6].

In addition, it is possible to use transponders or tags to send information about the users in a road, such as other vehicles or pedestrians, and also information about the driving conditions, in order to avoid accidents and traffic violations [5].

Frequency modulated continuous wave (FMCW) radars have been satisfactorily applied for quite long time for measuring the position and velocity of objects [7].

FMCW radars basically operate at frequencies of 24 and 77 GHz in the automotive industry. For a short range of up to tens of meters it is possible to use a radar of 24 GHz, while for a long range of about 250 m it is used a radar at 77 GHz [3], [5].

Various research works have been conducted from a technical perspective to evaluate different FMCW radar systems, both at 24 and 77 GHZ, for their use in the automotive industry [6–12]. How-ever, in this work it is considered the use of these radars from a different perspective, which besides evaluating their performance also focuses on their potential use as a didactic tool that enables enhancing the understanding of concepts which on many occasions may be quite complex to understand, such as the Fast Fourier Transform (FFT), the radars and their applications in telecommunications and in the automotive industry. For this purpose, it is proposed to use radar evaluation boards considering the benefits in the development of specific and transversal competencies in students.

1.1. Important parameters in an FMCW radar

In order to process and obtain position, velocity and angle it is necessary to consider different equa-tions, whose derivation may be found in [4], [13]. These equations are derived from the following gen-eral idea about the operation of an FMCW radar. The radar transmits a signal with a frequency that var-ies linearly (TX) and with a particular bandwidth, this signal is reflected by a body located in the radi-ated space of the antenna and arrives as a signal to the receiving antenna (RX) with a delay time pro-portional to the distance of the body. These signals are mixed to obtain a signal of intermediate fre-quency (IF), whose frequency is proportional to the distance of the body (Figure 1). Therefore, bodies at different distances will generate IF signals of different frequencies. On the other hand, small differ-ences in position will generate different phases of the IF signals which enables determining the velocity of the bodies [2], [4], [14].

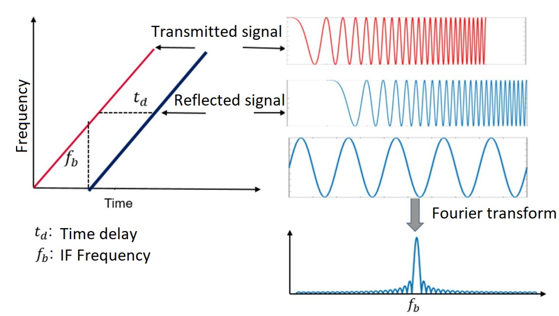

Figure 1. Basic principle of operation of an FMCW radar [15]

The value of the distance to a body is obtained from Equation 1.

$$R = \frac{cT_c f_b}{2B} \tag{1}$$

Where:

R is the distance of the object
c is the speed of light
T_c is the tiempo of the chirp
f_b is the frequency of the IF signal (beat)
B is the bandwidth

The distance resolution or capability to identify two objects close to each other is determined according to Equation 2.

$$\triangle R = \frac{c}{2B} \tag{2}$$

Where:

$\triangle R$ is the resolution
c is the speed of light
B is the bandwidth

The maximum distance may be determined as a function of the sampling frequency, according to Equation 3.

$$R_{max} = \frac{f_s c}{2S} \tag{3}$$

Where:

R_{max} is the range or maximum distance
f_s is the sampling frequency
c is the speed of light
S is the slope of the modulation $S = B/T_c$

On the other hand, the maximum velocity is given by Equation 4.

$$v_{max} = \frac{c}{4f_c T_c} \tag{4}$$

Where:

v_{max} is the maximum velocity
c is the speed of light
f_c is the frequency of the chirp
T_c is the time of the chirp

Now, in case of having different objects different frequencies will appear and, thus, instead of applying Equation 1, one of the most common techniques is to perform a spectral analysis from the fast Fourier transform (FFT) according to Figure 2, to obtain a Range-Doppler map.

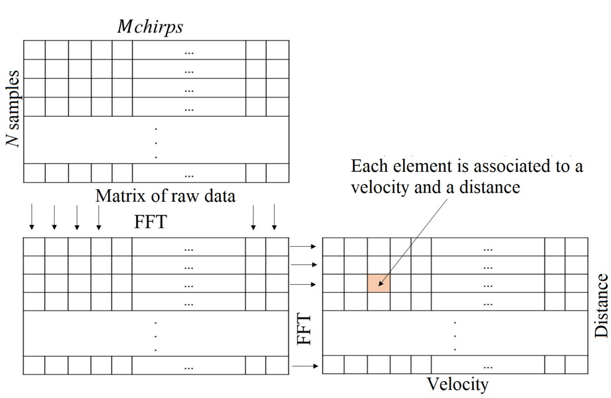

Figure 2. 2D Range-Doppler FFT

The angle of arrival (AoA) may be obtained from a 3D fast Fourier transform (3D FFT), such that the peaks of the frequency spectrum correspond to a particular angle, which is normally carried out when there are four receiving antennas and one or more transmitting antennas to obtain a multiple-input multiple-output (MIMO) array [8]. When the circuit has only two receiving antennas it is preferable to obtain the AoA from Equation 5.

$$\alpha = sin^{-1}\frac{\lambda\triangle\varphi}{2\pi d} \tag{5}$$

Where:

α is the angle of arrival
λ is the wavelength
$\triangle\varphi$ is the phase difference between the signal of the antennas
d is the distance between the antennas

1.2. Applications of radars in the automotive industry

In recent years radars have been employed in vehicles mainly for safety reasons, such as ADAS sys-tems, anticipating needs and taking the lead when necessary [16]. In the automotive industry, applica-tions of radars are mainly divided in short range radars (SRR), which enable blind spots detection (BSD), lane change assistance (LCA), cross traffic alert (CTA) in the front and rear areas, lateral impact alert and alert for cyclists in the lateral way (Figure 3). On the other hand, there are medium and long range radars (MRR and LRR) responsible for automatic emergency braking (AEB) in front of collisions with pedestrians and with other vehicles, as well as adaptive cruise control (ACC) [17].

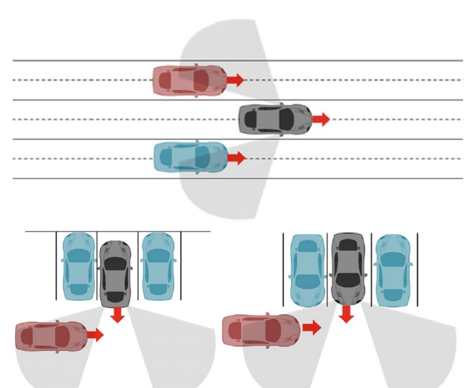

Figure 3. Example of short-range scenario. Detection of blind spots and cross traffic alert

The radar chosen in this work, whose features are detailed later, is a short range one and thus it re-sponds to the typical requirements shown in Table 1.

Table 1. Requerimientos de radar de corto alcance [17]

Requirements of the radar parameters	BSD Requirements	CTA Requirements
Range (m)	1-50	2-60
Range accurancy (m)	± 0,10	pm0,20
Range resolution (m)	0,75	1
Velocity (m/s)	-70 to + 70	-70 to + 70
Velocity accurancy (m/s)	± 0,1	± 0,1
Velocity resolution (m/s)	0,25	0,3
Azimuth (°)	±75	±40
Azimuth accurancy (°)	±5	±5
Azimuth resolution (°)	15	15
Elevation (°)	±6	±10
Elevation accurancy (°)	pm0,1	±5
Elevation resolution (°)	-	-

1.3. Didactic tools and competency-based learning

Among the aspects involved in engineering teaching, lab practices are of vital importance. According to [18], such practices must be capable of providing enough information that enables defining and charac-terizing activities in which students develop specific and transversal competencies.

For example, Arduino has been frequently employed in recent years thank to its ease of use and low acquisition cost [19]. This is something that has influence in countries where there are no adequate re-sources to acquire equipment which may be rather expensive, and therefore using low-cost development boards, in this case radar ones, may generate extensive benefits. Specifically, they enable improving access to devices which, as it has been mentioned, have almost been of exclusive use in the military and aeronautical areas. Similarly, it enables improving access to pioneer technology being developed in high, medium, and even low range vehicles. In this respect, it is important that future engineers and techni-cians are appropriately prepared in Latin America with the knowledge and competencies to be able to perform maintenance to vehicles and, similarly, participate in research and development in these areas, since current vehicles are equipped with a great number of electronic devices [20].

On the other hand, theory teaching benefits from and harmonizes with adequate experimental methodologies, not only in traditional labs (e.g., electronics or electric circuits), but also in those subjects that, traditionally, do not involve experimental activities, such as Mathematics.

2. Materials and methods

At present, different technological companies have brought to the market boards that in principle serve to evaluate the performance of the integrated circuits that they offer, such as the case of Analog Devic-es who offer the Demorad for different chipsets including the ADF5901 (microwave integrated circuit at 24 GHz with 2 transmission channels), ADF5904 (receiver of 4 channels at 24 GHz) and AD4159 (in charge of generating triangular chirps or saw tooth) and other circuits that provide a complete radar system integrated in a board [21]. Infineon also offers the Distance2Go [22] or Position2Go [23] boards, among others.

The Position2Go board has been chosen for this work since it is one of the simplest (from the point of view of the architecture) that can be found in the market, relatively easy to use and at an affordable cost. Its performance is evaluated for obtaining Range-Doppler maps, position and object detection by means of the CFAR (Constant False Alarm Rate) algorithm, which is one of the simplest to implement and understand from the didactic point of view.

2.1. Hardware

The Position2Go board includes all elements necessary for generating, receiving, and processing the signals. It is divided in four important sections: the radio frequency (RF) section includes the CI BGT24MTR12 that is the primary responsible for generating and receiving signals at 24 GHz [23], as well as three antennas, one for transmitting and two for receiving. It also has analog amplifiers that pro-vide an interface between the RF and the digital sections. It includes a frequency control section and a digital section, specifically it has a 32-bit XMC4700 ARM microcontroller to sample and process data, all this mounted on a board that enables access through a USB 2.0 connection that also has a CAN connection in case that a direct communication with an electronic control unit (ECU) of a vehicle is required. Therefore, it may be said that it is a complete radar integrated system that enables its direct control and programming by means of some connection protocols pointed out (USB has been used in this work). Figure 4 shows the general architecture of the board, while Figure 5 shows the board used in this work.

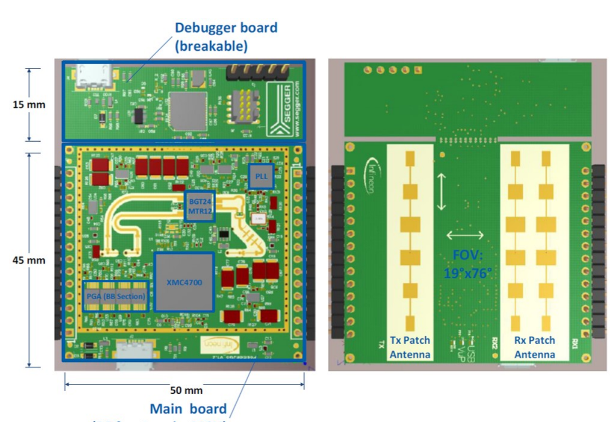

Figure 4. Position2Go Board

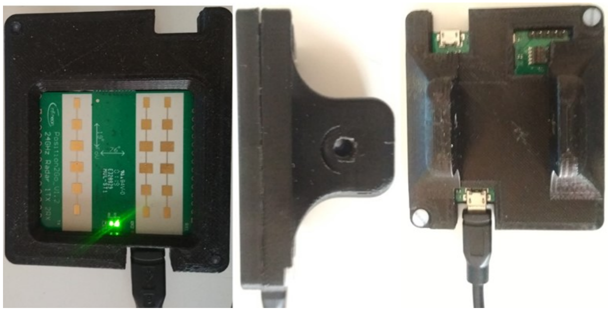

Figure 5. Position2Go board used

Table 2. System parameters

Parameters	Value
Up-chirp time: τup	301 μs
Down-chirp time:τ_{down}	100 μs
Standby time between chirps τ_{sby}	$100_{\mu s}$
Pulse repetition time: $\tau_{up} + \tau_{down} + \tau_{sby}$	$501_{\mu s}$
Bandwidth (B)	301 MHz
Sampling frequency (f_s)	850 MHz
Samples per chirp	256
Chirps per frame	16 (maximum)
Reach resolution ($\triangle R$)	75 cm^*
Minimum reach (R_{min})	0 m
Maximum reach (R_{max})	14 m^{**}

* Theoretical without windows
** Maximum distance to be evaluated

2.2. Experimental design

Position2Go includes a firmware that simplifies the control of the different ICs and peripherals through the XMC4700 microcontroller. This firmware enables performing changes in the configuration of the parameters of interest and provides the signals processed or unprocessed. There is a user interface to directly obtain the signal processed, generating the frequency spectrum and determining the position and velocity of the different objects [24]. This toolbox of Infineon (Figure 6) enables showing the calculations carried out by the microcontroller, taking into account that by default the calculations are performed with a threshold of 100 LSB, which results in a range of approximately 12 m for pedestrians and 15 m for a radar cross section (RCS) of 1 m^2 [25]. However, working with this interface limits the capability of processing the signals, and besides, it does not allow to obtain the didactic advantages sought for (although it may be a starting point). As a result, it is intended to acquire the IF signal and process it directly in MATLAB. For this purpose, an API is available which enables modifying and obtaining the values directly [26]. Table 2 shows the chosen features thanks to different lines of code implemented.

It must be emphasized that the conditions detailed are not typical for evaluation of radars. However, it has been preferred a scenario more quotidian and adaptable to the reality of a university for three reasons.

The first reason is that in the environment of a university lab it is difficult to have access to regulated conditions for a correct evaluation, such as the availability of an anechoic room (Figure 7) and square or triangular reflectors to avoid dispersion in the measurements, and in this way evaluating the accuracy and precision of the radar in an appropriate manner; just as the vehicles for tests, a static vehicle and a pedestrian are more feasible conditions in an educational environment. The second reason is that the FMCW radars at 24 GHz are used for short range and low speeds, as has been detailed previously. At last, the main didactic objective stated is the understanding and implementation of the theoretical as-pects and not of a deep evaluation of the features of the board used.

As an additional aspect it should be mentioned that due to the limitation to free circulation and the confinement during much of 2020 (especially between the months of March and July) and the closure of universities, measurements were carried out in a nonideal environment, due to the impossibility to access the working material that was in the labs.

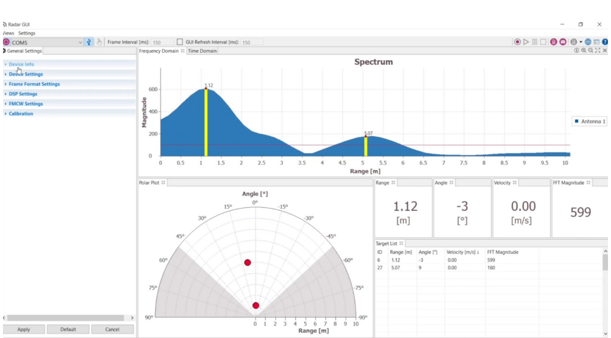

Figure 6. Radar GUI of Infineon

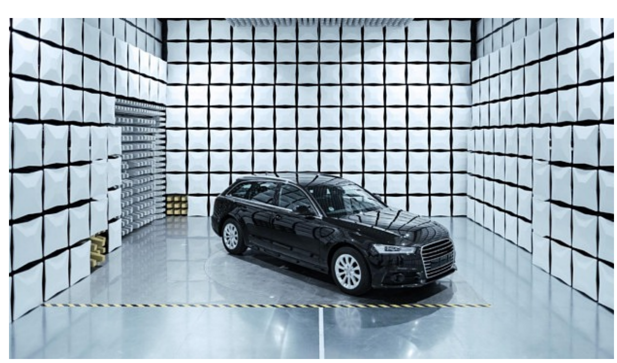

Figure 7. Anechoic room [27]

To carry out the measurements it has been considered the following scenario according to Figure 8, where it has been taken into account a static vehicle at a distance of 2.9 m, a static pedestrian at a distance of 7.5 m, a wall at a distance of 12.3 m, and besides a pedestrian who runs in a straight line from the initial position of the radar up to the wall and returns.

From the configuration detailed in Figure 8, different measurements were carried out considering the data (IF signal) provided by the firmware directly to MATLAB, where each measurement has 50 dataframes, by means of a for loop that can be modified to obtain the desired number. A dataframe consists of the raw data to be processed (IF signal) with different functions implemented in MATLAB.

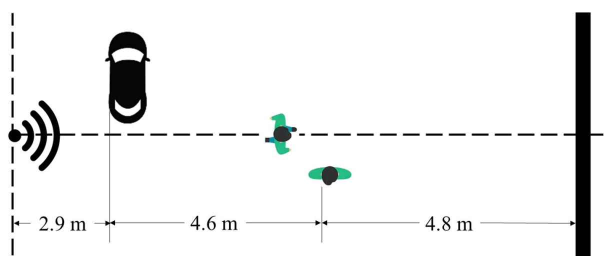

Figure 8. Measuring scenario

2.3. Processing in MATLAB

Data processing may be summarized in 4 levels. First, define the parameters detailed in Table 2 following the methods listed in *26*, calculate the measuring limits from the equations detailed, define the window to be applied, in this case it was chosen a Hamming window with the purpose of reducing the amplitude of the lobes adjacent to the main peak in the FFT, reorganize the data, since the firmware by default sends the data in a three-dimensional array. The first dimension contains all the samples per chirp for estimating the distance; the second corresponds to the different chirps per frame for estimating the velocity and the third corresponds to the antenna; however, it has been chosen to work in two three-dimensional arrays, one for each antenna and substituting the third dimension for the measurement number such that two arrays of size $N \times M \times L$ were obtained, where N is the number of samples per chirp limited in frequency corresponding to the interval of distance (*2,14* meters); M is the number of samples per frame, which corresponds to $M = 16 \times 256 = 4096$; and finally L measurements, being L=50 measurements in this case. The interval between measurements has been 0.2 s.

Then it was applied a first FFT to the first chirp in order to obtain the distance spectrum with a size of 2^{12}, therefore, $2^{12} - N$ elements are filled with zeros using zero padding, which is automatically carried out in MATLAB (see [28]); the purpose is increasing the resolution such that it is simpler to recognize two frequencies close to each other [29]. This results in the so-called Range-FFT.

Afterwards, a new FFT is applied, but this time through the different chirps, in order to obtain the Range-Doppler map.

At last, the CFAR algorithm has been applied to identify the different objects from what is detailed in [30]. This board has the disadvantage of being limited in bandwidth (200 MHz for 24 GHz) and in number of chirps/frame, therefore, the size of the cells for the application of the CFAR must be high, and in this case it was chosen 90×90 of guard and 30×30 of training, with a factor $K = 10^{8/20}$. A flow diagram with a generalization of the algorithm used is shown in Figure 9.

The programming has been developed from the demos of Infineon *23*, Analog Devices *21* and the work by Guerrero *11* applied to other development board. However, these programs have been broadly modified to include:

Capability to export recordings (.AVI) in MATLAB

Capability to create and export polar plots of the position of the bodies.

Capability to isolate and analyze desired dataframes.

Application of CFAR algorithm.

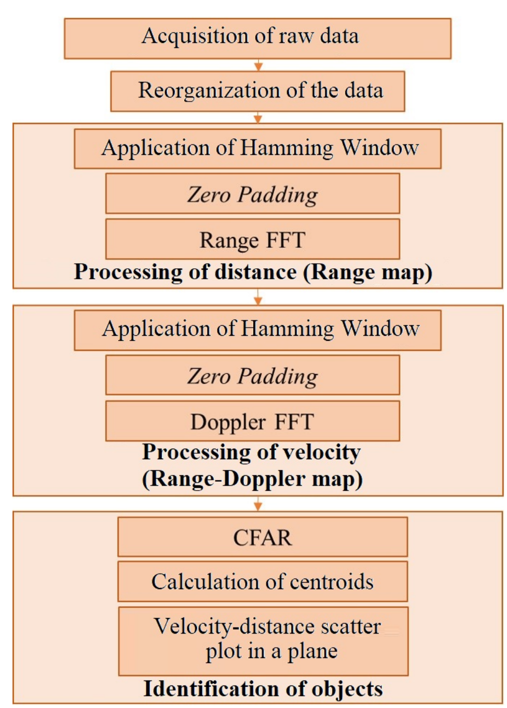

Figure 9. Signal processing diagram

3. Results and discussion

3.1. Firmware and Infineon Toolbox

From the data directly processed by the microcontroller, it was obtained the Range-Doppler map shown in Figure 10, in which it is seen various false detections or misdetections because the threshold is fixed by default as has been detailed previously.

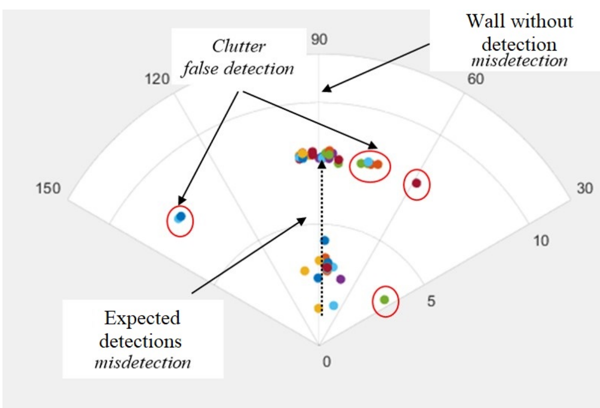

Figure 10. Measurements from the firmware

On the other hand, although this first approximation for stu-dents may seem sufficient, the fact that only processed data are shown limits the objectives sought for when using the board, i.e., it is not evaluated didactically the obtention of the results, but they are only shown without deepening in the algorithm employed for this purpose. Even though a modification of the algorithm and a direct implementation of the CFAR in the microcontroller is possible, its implementation is not simple and for this reason the rest of the results shown were obtained using the MATLAB implementation.

3.2. MATLAB

The Range-Doppler map of Figure 11 has been selected among the 50 maps generated; in this map it is possible to appreciate the bandwidth problem of the radars of 24 GHz of 200 MHz, i.e., that they do not have a good distance resolution, and in addition the chirps per frame of the Position2Go are limited to 16 by default, when in other boards of 77 GHz it may be obtained, for instance, up to 128 chirps per frame.

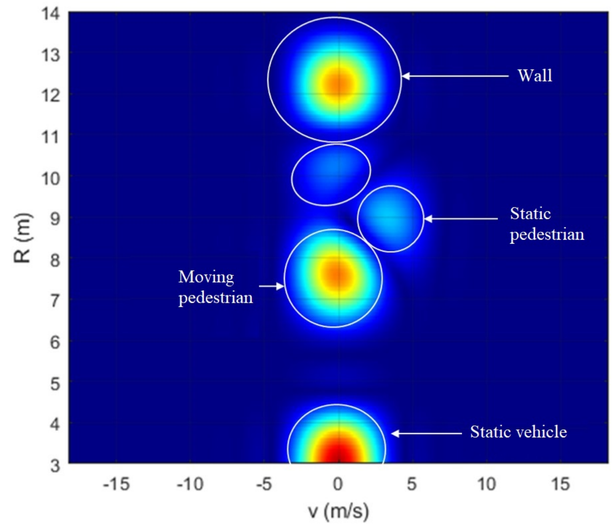

Figure 11. Range-Doppler map

Five areas may be seen in Figure 11 corresponding to relative maxima in the FFT; the identification by means of algorithms that enable automatic discrimination between the different bodies that may be in the environment is out of the scope of this work, particularly because the study has been stated as a tool for undergraduate environments, which implies a limited complexity.

At this point it is important to clarify to the student that although this map enables a fast visual identification, it is not very practical from the computational point of view because a microcontroller by itself would not be capable of identifying the bodies without an additional algorithm in charge of that (one of these algorithms is detailed in-depth in [31]). It is at this point where the application of the CFAR algorithm simplifies to dynamically obtain a detection limit, so that it is considered the signal-to-noise ratio (SNR). It is important to remark that the CFAR by itself is not capable of carrying out the discrimination about the bodies (vehicles, pedestrians, motorcycles, etc.)

Since the K factor has been configured to a relatively low value, this results in many areas when applying the CFAR (Figure 12). To overcome this issue, it has been only taken those points that have a power of at least –40 dB, value empirically obtained from various measurements (for a smaller power it generally resulted in false detections), this value may be also dynamic, considering that the power reflected depends on the radar equation which in turn depends on the distance at which the body is lo-cated; at the same time, the reflection levels are different according to the object, for example, a vehicle reflects more power than a pedestrian, considering that the electromagnetic waves (such as the ones transmitted by a radar) are reflected in the bodies according to the radar cross section which depends on different factors such as the area, the material (of the clothes or of the vehicle), the shape, etc., and this may be used to be able to classify the bodies. Table 3 shows some of the values obtained from the centroids for each of the areas (Figure 13).

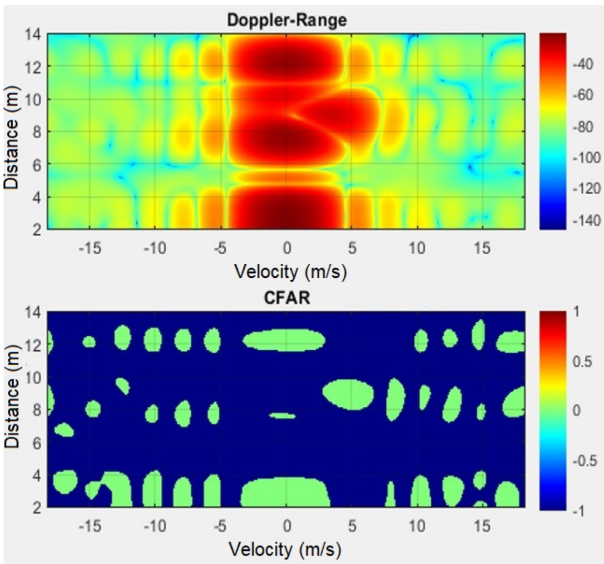

Figure 12. Range-Doppler map in dB and result of CFAR

Figure 14 shows the objects detected considering the –40 dB limit. Then, it is evident that the CFAR enables identifying objects correctly, even when the velocity of the pedestrian has been slightly higher than the real one (Table 4); in this sense, it is a contribution of this work to the detection of ob-jects with respect to the one carried out by the Infineon graphical interface. It is clarified that the results have not been optimized, and in this way, it may be shown conditions in which a student might imple-ment a non-optimized algorithm and even obtain acceptable results.

Table 3. Data sorted considering the power

Distance (m)	Velocity (m/s)	Power (dB)
2,8564	–0,0803	–21,1564
7,5806	–0,2945	–23,2399
12,2498	–0,0803	–23,3293
8,9539	4,8109	–33,7255
2,9114	–5,6320	–53,0894
⋮	⋮	⋮

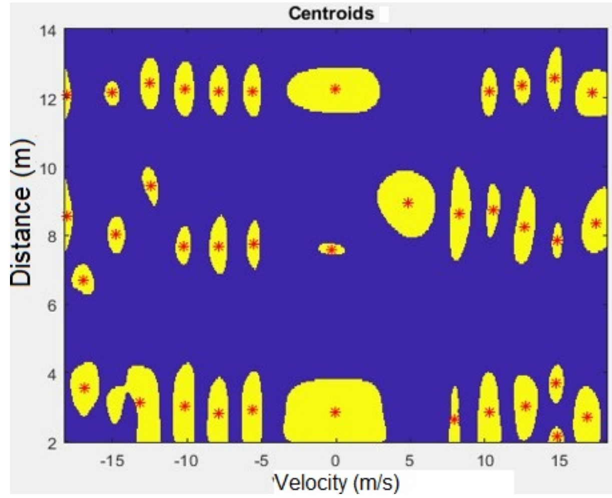

Figure 13. Centroids from the CFAR

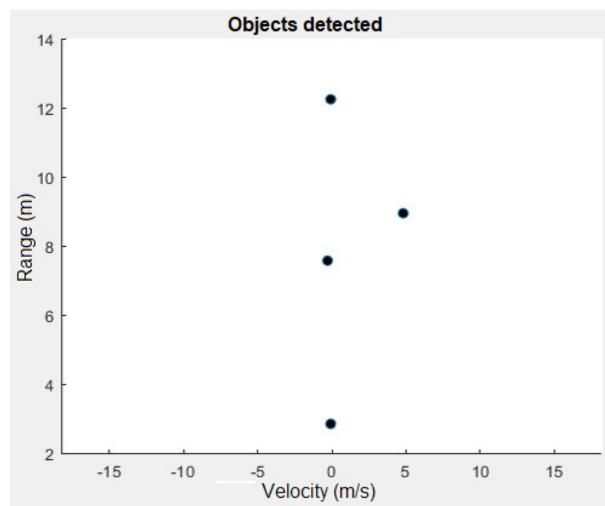

Figure 14. Identification of objects using CFAR

Table 4. Data sorted considering the power

	Measured distance (m)	Real distance (m)	Measured velocity (m/s)	Real velocity (m/s)
Vehicle	2,8564	2,9	–0,0803	0
Static pedestrian	7,5806	7,5	–0,2945	0
Wall	12,2498	12,3	–0,0803	0
Moving pedestrian	8,9539	≈ 9	4,8109	≈ 4

Figures 11 – 14 show one of the frames of one of the measurements that has been chosen; due to the structure of this document all of them cannot be shown. However, Figures 15 and 16 show the distances obtained from the application of the CFAR in each of the dataframes. Figure 15 shows the moving pedes-trian, where an effective detection rate of 78.57% is achieved (without considering false detec-tions and misdetections). On the other hand, Figure 17 shows the dispersion for the static bodies. Table 5 details some statistical values that are within the values of Table 1. However, it is important to remark that the precision and accuracy shown does not necessarily reflect the real values of the radar, due to the aforementioned constraints. The importance of these results lies on the fact that even in non-optimal conditions, the radar achieves good precision and accuracy, and thus it is expected that students yield adequate results without requiring a deep calibration and more complex algorithms.

From these results, the use of this evaluation board emerges as an appropriate tool to be employed in lab practices, because it covers specific competencies: understanding of mathematical fundamentals such as the Fourier transform, complex numbers, operations with matrices, spectral analysis, among oth-ers, as well as fundamentals of physics: kinematics, electromagnetic waves, Doppler effect, etc. On the other hand, with an adequate guide of the teacher it may be promoted transversal competencies accord-ing to [32], such as: computer concepts related to the area of study, specifically it is promoted the use of MATLAB and other computational tools. Similarly, it may be encouraged the work in teams, auton-omous learning, adaptation to new situations, capability of applying theoretical concepts in the practice, use of the Internet as an information source, among others.

All the previously mentioned in an adequate environment, which does not generate frustration on the students and an appropriate tutoring may translate in a great impact in their education.

Unfortunately, no previous case studies were found about the viability of the proposal of using ra-dars as a didactic tool and the evaluation of the impact. Therefore, this is the reason why this work ana-lyzes the viability both technical and didactic of using an evaluation board of the many available in the market.

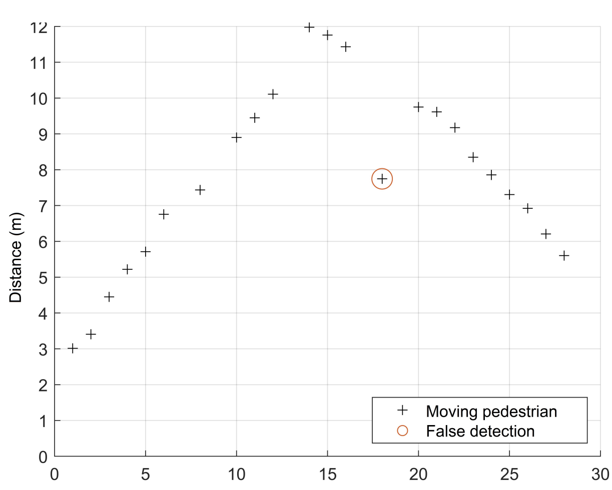

Figure 15. Identification of objects using CFAR

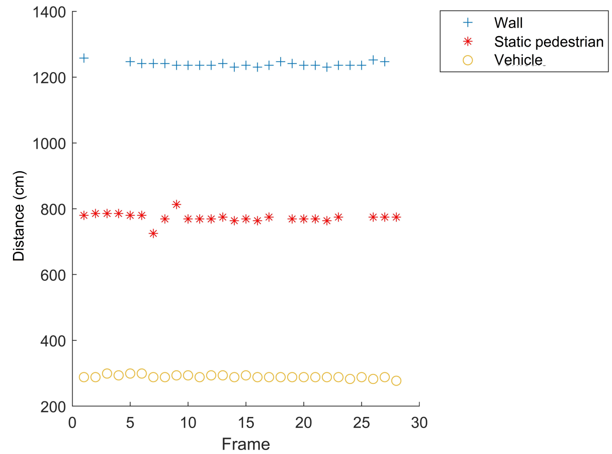

Figure 16. Identification of objects using CFAR

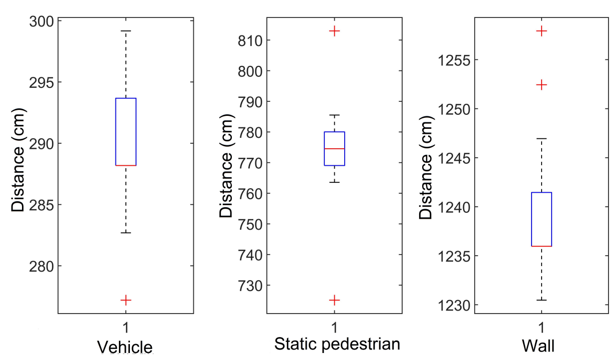

Figure 17. Identification of objects using CFAR

Table 5. Statistics for measuring the distance of the static bodies

Distance			
Real (cm)	**Mean (cm)**	**Median (cm)**	**Standard deviation (cm)**
290	289,75	288,18	4,84
750	773	774,54	14,03
1230	1239,40	1235,96	6,69

4. Conclusions

This work shows an evaluation board based on a FMCW radar which operates at 24 GHz with a bandwidth of 200 MHz. The empirical performance without considering a statistical analysis that enables determining the rate of false detections and without a precise calibration, it is more than acceptable for its use as an educational tool with the purpose of understanding the operation of short-range radars and their application in vehicles. Obtaining and processing data is relatively simple, thus helping in the de-velopment of both the researcher and the teacher who desires it. However, it is recommended to start by the application of an algorithm that involves the two-dimensional fast Fourier transform to obtain Range-Doppler maps, and then to use a CFAR algorithm for improving the detection of objects with respect to the implementation of a fixed limit. In case it is desired to deepen in the classification of bodies, it is recommended to investigate about the different algorithms available.

Although it has not been compared with other boards, the results obtained and the low cost of the Position 2Go show that implementing its use in lab practices in Automotive and Telecommunication Engineering careers may result in many benefits in the development of specific and transversal capaci-ties of students.

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