Doctoral School on Engineering Sciences
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Extended summary

Evaluation of Spread Spectrum Techniques Performances in Aerospatial Monitoring Applications

Curriculum: Ingegneria Elettronica, Elettrotecnica e delle Telecomunicazioni

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Abstract. This paper aims to analyze and integrate different aspects of telecommunication technologies in space environment, in order to monitor data from sensors in space. One aspect is the sensors monitoring on board; proposes the use of a UWB RADAR device which is completely analyzed, developing and comparing two different detection methods, the frequential one and the method based on the mapping of correlation peaks delays, from received UWB RADAR signal. The RADAR detects breathing and hearbeat frequency of a human being through these methods. A channel model chest is described to evaluate the effect of the wave signal reflections due to inner layers . In addition, the signal processing is discussed to solve the problem created by the reflection due to fixed obstacles , so-called static clutter , evaluating different algorithms performances (MS , RPS , LTS , DMF). The chest signal movement extraction allows tracking and studying certain respiration disorders as obtaining also information on heartbeat rate. The Radar device can be integrated with WBAN; a streamlined proposal for low- energy impact, based on PPAM UWB, is mentioned to monitor astronaut vital signs. Further aspect of spread spectrum communication technologies in Aerospatial scenarios, where relative velocity due to movement between the source and destination are high and cause a considerable Doppler, are investigated; for example the data originating from the spacecraft. Some doppler shift and synchronism recovery schemes are shown, using spreading sequence families (Gold, Chaotic and De Bruijn) analyzing and comparing them through the Ambiguity Functions, in order to study an uncompensate Doppler shift receiver effect, such as a system in orbit with essential reduced electronic, both in the case in which it owns a compensate Doppler shift receiver but the demodulated signal is affected by code doppler, that generates distorted autocorrelation functions from the received spreading sequences.

Keywords. Aerospatial, Doppler, Monitoring, Radar UWB, Spread Spectrum.

1 Problem statement and objectives

In recent years some of the most well-known studying activities were incorporated in space and biological behaviors of living beings on board real laboratories in orbit around our planet, such as those on the International Space Station[1]. Similarly, astronauts vital sign parameters and data monitoring of sensors probes which have been sent on planets of the solar system, is important in the space environments[2,3]. The communication scenario that comes to mind is the one where the transmitter and receiver are in relative motion, and the received signal is affected by strong Doppler effect[4].
The objectives are:

- studying and comparing several UWB radar detection techniques and channel modelling that allow knowing vital signs parameters;
- showing for a possible UWB radar integration with a PPAM UWB;
- analyzing a DSSS communication behavior between spacecraft in motion that generate strong Doppler on the received signal, in order to support the astronaut's vital parameters monitoring on vehicle or other sensors installed on spacecraft traveling in deep space.

2 Research planning and activities

At first the research activities focused on studying and implementation of various channel modeling and received UWB Radar signal algorithms in MATLAB environment; the natural prosecution has been compared several clutter removal (MS , RPS , LTS and DMF), and detecting (frequential and based on the mapping of correlation peaks delays method) algorithms. A second research activities focused on studying and implementation of a new Physical layer protocol for Wireless Body Area Network, based on UWB PPAM transmission techniques, for energy efficient. Other research activities focused on studying and implementation of the Ambiguity Functions and fast method to calculate them, studying Code Doppler phenomenon and to implementation of Doppler and synchronism recovery schemes based on PLL, using direct sequence spread spectrum and several sequence families (Gold, Chaotic and De Bruijn).

2.1 RADAR UWB

Non-invasive sensing of respiratory and circulatory movements with microwave Doppler radars was developed in the '70s and the '80s. The UWB radar systems can be used for remote vital-signs monitoring, with the major applications of these systems being in health monitoring and rescue scenarios [8,9,10,11].

2.1.1 Channel modelling

In Figure 1 is shown the UWB Radar system. The channel model contemplate two contribution, one take into account the movement, and the second take into account the fixed replicas, in according at the formula:

$$h(t,\tau) = h_s(t,\tau) + h_m(t,\tau)$$

$$h_s(t,\tau) = \sum_{i=0}^{M-1} A_i \delta(\tau - \tau_i)$$

$$h_m(t,\tau) = A\delta(\tau - \tau_d(t)).$$

Three movement channel models $h_m(t,\tau)$ are developed, the simplest take in account only chest reflecting signal movement(one tap channel), the others take into account the human body effect (tapping channel). One approximate the response of all internal tissue at a specific frequency, and one model approximate the body with a transmission lines with variable length and the response takes into account the frequency response of every tissue. This preliminary study allows to evaluate the internal response for search the heartbeat information.

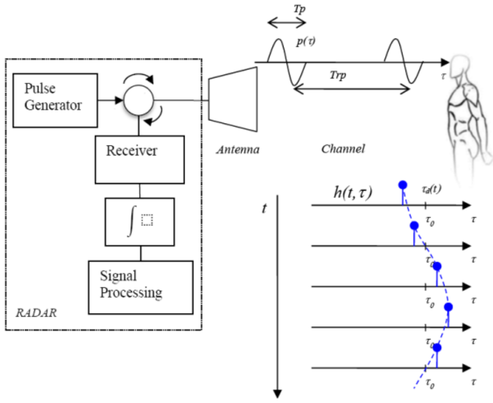

Figure 1

2.1.2 Detecting methods

Two methods for respiratory movement detection are well know; the classical approach extract the delays correlation peaks due the movement and allow chest movement reconstruction[10,13]; frequency approach uses received UWB matrix signal to compute the FFT and extracts frequency peak values from it [8,11].

2.1.3 Clutter removal tecniques

In order to extract respiration rate information from received UWB radar signal, it's important eliminating "background clutter"; this undesired signal components are caused by antenna ringing, antenna cross talk, wall, and fixed object reflections and non-ideal pulse generator; the $h_s(t,\tau)$ contribution allows consider the static clutter and in order evaluating the Motion Filter algorithms (MS , RPS , LTS , DMF) [12].

2.2 UWB PPAM transmission techniques, for energy efficient

In Aerospatial context an efficient energy technique is important and it allows transfer a very limited amount of data, assuming a network of maximum ten sensors, it means a multi-users scenario, low power, enough to cover short distances of few meters[15].

In Fig.2 is shown the scheduling of transmitting protocol and the equation below represents the signal expression:

$$s(t)=\sum_{i=-\infty}^{+\infty}\sum_{j=0}^{Ns-1}A_j^i m_g\left(t-iT_{rt}-S_{tx}^i-jT_f-c_j^iT_c-\delta d_j^i\right)$$

One of the sensors can transmit in a random manner with respect to other sensors, every Trt time and it transmit Ns PPAM symbols for every Trt duration. The data information is coupled with the amplitude A_j meanwhile the identification is coupled with the position δ . By exploiting the correlation properties of the pseudonoise sequences used to identify each sensor, it is possible to recognize the specific sensor ID at the receiver, by setting a proper threshold value on the received sequence correlation.

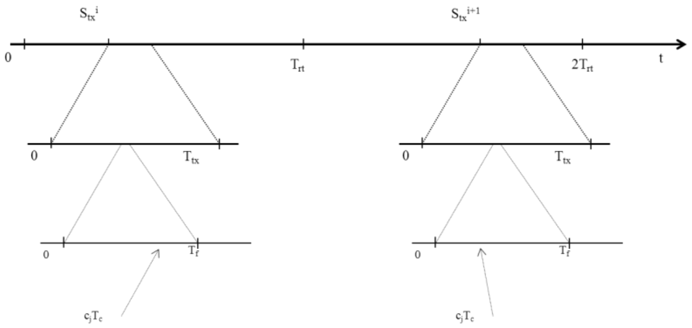

Figure 2

For evaluating the BER performance it is condidered BER includes two contributions:
- thermal noise effect only, when Eb/N_0 is low;
- overlap of interfering signals only, when Eb/N_0 rate is high

The last one depends on the probability of collision due to several users (PI):

$$BER \approx BER_N + BER_{MAI}\cdot PI$$

2.3 Doppler effects on spreading sequences in DSSS

The impact of Doppler shift on the acquisition performance is two-folds: carrier-frequency offset, and code-frequency offset [5]. If the Doppler shift is small, code-frequency offset is so small that it can be ignored, and only carrier-frequency offset shall be faced. The Ambiguity Function (AF) tool may be used to cope with such a case. In severe Doppler conditions, however, code-frequency offset can also be significant. Code Doppler gives rise to the code chip slipping during the correlation process. Moreover, the power reduction through the bandpass filter, caused by carrier Doppler, can degrade the acquisition performance significantly. In certain applications, acquisition in the presence of data modulation and severe Doppler shift is necessary, as in the case of high dynamic GPS receiver [6]. Pseudonoise sequences, used as spreading codes, play a fundamental role in SS systems: their auto- and crosscorrelation properties affect the performance obtainable, in terms of capability of generating noise-like signals, and reducing multiple user interference. Besides traditional and wellknown families of binary sequences, such as maximum length sequences (also known as m-sequences), Gold and Chaotic. A preliminary performance analysis of Direct Sequence Spread Spectrum signals, obtained through the use of innovative binary spreading sequences, De Bruijn and Chaotic, in a scenario of large Doppler shift, and relative changing rate, as a result of the possibly high varying velocity of an aircraft, and worst-case condition of missing frequency offset estimation capability onboard[7].

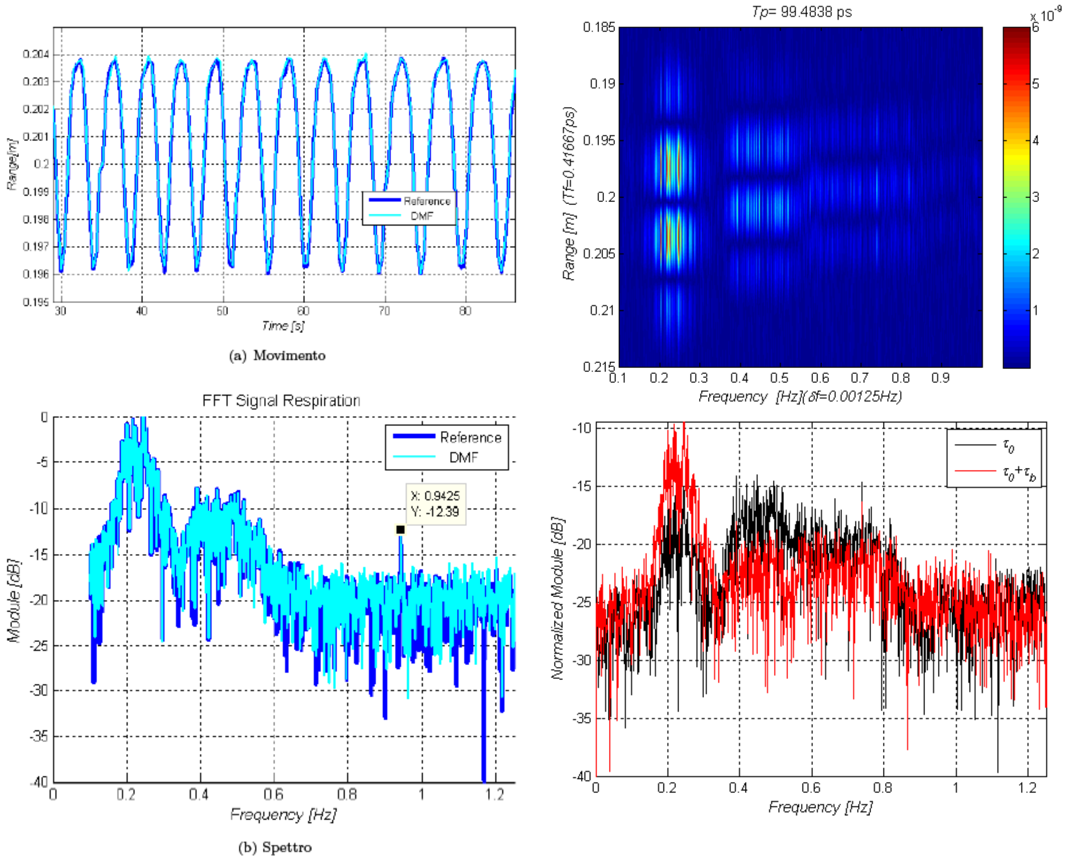

Figure 3

3 Analysis and discussion of the main results

3.1 RADAR UWB

The UWB radar methods have been simulated and compared. With the same parameters, as the sampling fast time T_{ft}=0.416ps, the frequencial method not allow obtaining the hearbeat frequency. Instead the extraction of the delays correlation peaks from received signal allow obtain both the hearbeat frequency and the chest movement which permits studying breath pathologies [18]. In Fig. 3 shown the result of the frequencial method at right side, and the delays correlation peaks method at left side, with a real breathing signal and a heartbeat tone f_h =0.943Hz.

The performance of several stationary clutter suppression methods are evaluated for the purpose of UWB-radar-based respiratory motion detection by computing Pearson correlation coefficient at several Signal to Noise Ratio (SNR). Fig. 4 shown the main result and it's possible establish that the DMF is better than other methods with 5dB gain.

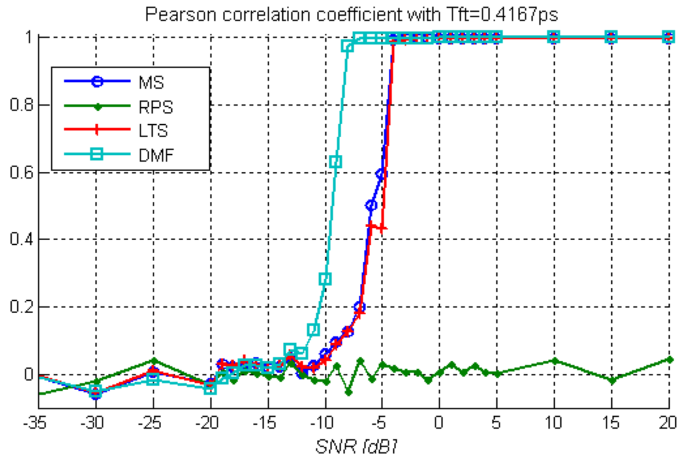

Figure 4

3.2 UWB PPAM transmission techniques, for energy efficient

The PPAM UWB protocol allows using of UWB radar device, because the radar deterministic pulse doesn't disturb the WBAN, and the previous study remains valid. However from radar part it's necessary implement a incorrelated slow time spike removal algorithm from received signal.

The sensors data can be interlaced to main data vehicle and can be transmitted to Ground Station with a Direct Sequence Spread Spectrum technique.

The WBAN guarantees low BER using limited number of symbols from sensor (Ns) and large Time repeting transmission (Trt). The Fig. 3 show the BER performance using fixed and variable pseudopattern c_j and Table 1 reports the BERfloor from several sensor in network (K)

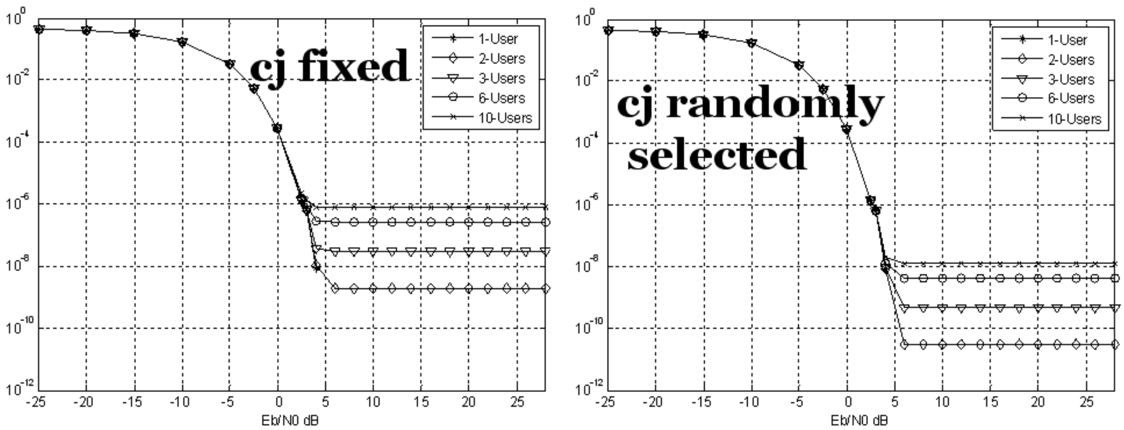

Figure 5

Table 1. BER Floor with Ns=64 and Trt=1s, in random and constant cj's case

K	2	3	6	10
c_i=rand	$3.09*10^{-11}$	$4.68*10^{-10}$	$4.29*10^{-9}$	$1.24*10^{-8}$
c_j=const.	$1.98*10^{-9}$	$3*10^{-8}$	$2.75*10^{-7}$	$7.94*10^{-7}$

3.3 Doppler effects on Spreading sequences in DSSS

Specific evaluation tool, represented by the Ambiguity Function (AF), typically applied for waveform analysis and used to estimate the radar performance provided by the selected sequence. The AF represents the time response of a filter matched to a given finite energy signal, when the signal is received with a delay and a Doppler shift (τ, υ) relative to the nominal null values expected by the filter itself. To get an ideal range and Doppler resolution, the AF value should be maximum in (τ, υ) = (0,0) and zero elsewhere, but this configuration is actually unfeasible. In this paper, the AF is applied to compare the performance obtainable by the adoption of De Bruijn sequences with respect to alternative families of sequences (Gold and Chaotic sequences), for different modulation schemes and pulse shaping functions. A generic numerical comparison among the different AFs is provided, in order to give a general overview of the behavior of the sequence sets in terms of Delay and Doppler. Then, a specific use case is considered, referred to the scenario of critical Spacecraft-to-Earth communications for Mars Exploration Rover (MER) Entry, Descent and Landing [14]. In the scenario herein considered, the velocity of the spacecraft, with its planetary lander and the rover, was approximately 7Km/s. It can compute the corresponding Doppler shift values, for a reference frequency of 7.75 GHz (X-band)[16]. In Fig. 6 are shown the results, from left to right the De Bruijn, Gold and Chaotic mean AFs.

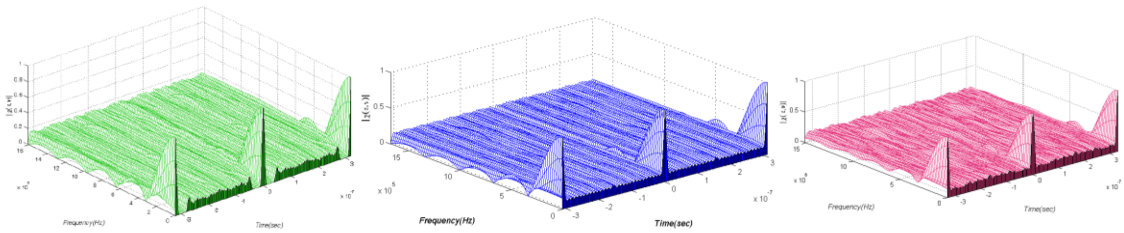

Figure 6

Different sets of spreading sequences are analyzed, in order to compare the performance provided at the receiver, in the presence of uncompensated code Doppler. To ensure a fair comparison De Bruijn sequences of even length, equal to 2^n for n=5,6,7,8,10 are compared to binary Chaotic sequences of the same length. On the other hand, Gold sequences of length 2^n-1 for n=5,6,7,8,10 are compared to binary chaotic sequences of the same length, under the same Doppler conditions. Due to the huge number of sequences to compare, in each set, an average evaluation is carried out, meaning that, for each set of sequences, an average auto-correlation profile is computed, as the chip-wise sum of all the auto-correlation functions, divided by the cardinality of the set. At the receiver, assuming that the Doppler effect is not compensated, the correlator computes a *generalized* auto-correlation function, because the locally generated spreading sequence and the received one are not actually the same[17]. The effects of uncompensated code Doppler are basically a reduction of the auto-correlation peak value, a variation of the sidelobes amplitude, and a shift in the time position of the peak and sidelobes, within the generalized auto-correlation profile of the sequences.

Table 2. Cardinality of spreading sequences families for different span *n* values

	De Bruijn subset		Chaotic subset	
n	length	# seq.	length	# seq.
5	32	1000	32	1000
6	64	1000	64	1000
7	128	129	128	129
8	256	257	256	257
10	1024	999	1024	999

	Gold		Chaotic subset	
n	length	# seq.	length	# seq.
5	31	33	31	33
6	63	65	63	65
7	127	129	127	129
8	255	257	255	257
10	1023	1025	1023	1025

Table 3 reports the normalized peaks and main sidelobes of De Bruijn (DB) and chaotic (C) sequences of length 1024, in ideal condition (Id) and in the presence of Doppler (D), and corresponding variations (Δ) at relative velocity of 12Km/s. Table 4 reports the same results for Gold (G) and chaotic (C) sequences of length 1023.

Table 3

		Peak	Sidelobe Values	
G	Id	1	9.54E-07	9.54E-07
	D	0.998235	2.98E-06	2.55E-06
	Δ	-0.17%	212%	167%
C	Id	1	0.056954	0.029605
	D	0.998241	0.056941	0.029591
	Δ	-0.17%	-0.02%	-0.04

Table 4

		Peak	Sidelobe Values			
DB	Id	1	0.00592	0.00407	0.003879	0.003726
	D	0.998221	0.00591	0.00406	0.003838	0.003744
	Δ	-0.17%	-0.23%	-0.24%	-1.05%	0.48%
C	Id	1	0.062504	0.032423	0.030403	0.025588
	D	0.998196	0.062486	0.032582	0.030434	0.025557
	Δ	-0.18%	-0.028%	0.49%	0.10%	-0.12%

A simulation with an extreme condition of radial velocity v_r = 120 Km/s is considered, in order to better evidence the impact of the uncompensated Doppler on De Bruijn and chaotic sequences of length 1024, which is responsible for the reduction of the auto-correlation peak value, and a time shift of its location, as shown in Fig. 7.

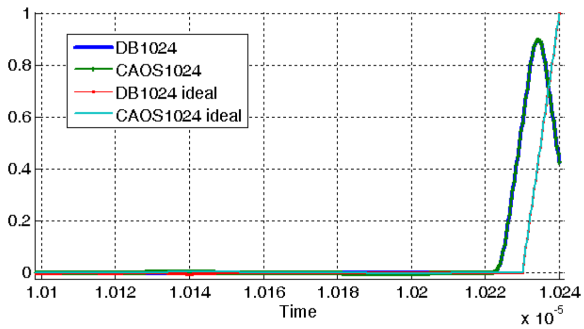

Figure 7

4 Conclusions

In this work, have been analyzed and integrated different aspects of telecommunication technologies in space environment, in order to monitor data from sensors in space environment. It has been shown by numerical comparing of received UWB Radar signal algorithms for detection, and for clutter removal, determining better performances. It has been shown it is possible extracting chest movement and the heartbeat frequency, even with presence of fixed obstacles, with consequently advantage resulting from study of breathing pathologies.

It has been shown radar device can be integrated with WBAN; a streamlined proposal for low- energy impact, based on PPAM UWB, has been mentioned to monitor astronaut vital signs.

It has been provided a comparison among the set of binary De Bruijn sequences of span n=5,6,7,8,10 and well known sets of sequences, such as Gold and Chaotic ones, to evaluate their possible application in Aerospatial scenario where spread spectrum techniques may be of interest. The performances provided at the receiver have been compared, in the presence of Doppler shift and the effect in the presence of uncompensated code Doppler.

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